The University of Alberta

The Precambrian Geology of the Needle Falls Area, Saskatchewan

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements for the Degree
of Doctor of Philosophy

Faculty of Graduate Studies
Department of Geology
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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Precambrian Geology of the Needle Falls Area, Saskatchewan", submitted by Peter Lawrence Money, B.Sc., M.Sc., in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

ABSTRACT

Rb-Sr whole rock dating indicates that the oldest rocks in the Needle Falls area are the western granitic rocks, with the possible exception of some inclusions of mafic metamorphic rocks. The western granitic rocks ($\sim$2300 m.y. old or older) are mainly quartz monzonite and appear to be of igneous origin. The available evidence suggests that they are unconformably overlain by two groups of metamorphic rocks, the "older metamorphic rocks" and the "cordierite-garnet rocks". The "older metamorphic rocks" are unconformably overlain by the Meyers Lake Group. The relationship of the "older metamorphic rocks" to the "cordierite-garnet rocks" is uncertain. Migmatitic and metasomatised rocks derived from the metamorphic rocks are of widespread occurrence. Younger intrusive rocks include epidiorite, hornblende quartz diorite, the eastern granitic rocks (mainly biotite quartz diorite and granodiorite), pegmatite, and quartz veins. No consolidated rocks in the area are known to be younger than the Hudsonian orogeny, which is dated at $\sim$1750 m.y. by K-Ar dating of micas.

The "older metamorphic rocks" were probably deposited in an intracratonic basin or geosyncline. They consist of metamorphosed arkosic wacke, greywacke, and basic to acidic volcanic (?) rocks. The Meyers Lake Group consists of a basal quartz-pebble meta-conglomerate, overlain by metamorphosed quartz arenite, feldspathic arenite, and pelites. This group was deposited during a period of relative stability in the area. The "cordierite-garnet rocks" consist of metamorphosed pelites, arkose, and minor calc-silicate rocks within the thesis area.

Most of the metamorphic rocks belong to the andalusite-sillimanite series, amphibolite facies, of Miyashiro (1961). Rocks belonging to the granulite facies, hornblende granulite subfacies, occur as inclusions in granitic rocks. A minimum temperature of about 520°C and maximum pressure of about 8 kilobars are suggested for rocks belonging to mineral zone C of the amphibolite facies. A maximum depth of burial of about 28 kilometers and a minimum geothermal gradient of 22°C/km

have been calculated.

The metamorphic rocks occur in two main fold belts. In the eastern fold belt the fold axes plunge gently to the north-northeast and south-southwest. The limbs are nearly vertical and the folds are isoclinal or nearly isoclinal. There may be some cross-folding. The folds in the western fold belt are probably similar in style and orientation. Northeasterly longitudinal and north-northwesterly transverse faults occur.

The "cordierite-garnet rocks" can be traced north-northeast for some 400 miles, and the "older metamorphic rocks" are traceable north-northeast for at least 75 miles, a feature of interest in regional correlation.

ACKNOWLEDGEMENTS

The field work on which this thesis is based was carried out under the auspices of the Precambrian Division, Geological Sciences Branch, Saskatchewan Department of Mineral Resources. The writer is grateful to the department for the opportunity to do this work, for granting leave of absence to work on a doctorate, and for financial and other assistance. Thanks are also due to the twelve students who aided the writer in field mapping, and especially to Blaine Scott and Owen Younge, senior assistants.

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Lastly, I would like to express my very deep gratitude to my wife, Frances, without whose encouragement and aid this thesis would never have been completed.

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INTRODUCTION

General Statement

The Eulas Lake Area (West Half), which is part of the Needle Falls area (see Figure 1), was mapped by the writer in 1961 for the Saskatchewan Department of Mineral Resources on a scale of one inch to one mile. The area was primarily assigned formapping because earlier one inch to four mile mapping (McLarty, 1936a) suggested the presence of abundant volcanic rocks. A secondary consideration was that on a regional basis the area appeared to be near the central axis of the Hudsonian orogenic belt and few areas along this axis have been studied in any detail. During the course of the mapping it became evident that the "volcanic rocks" previously reported were not present but the geology was sufficiently interesting that further mapping was carried out in 1962 (Sandfly Lake Area, East Half) and in 1963 (Black Bear Island Lake Area, West Half).

The Needle Falls area is underlain by a variety of intrusive and metamorphic rocks. The metamorphic rocks occur in two main fold belts of differing mineralogy. This thesis is primarily a study of the metamorphic rocks of the area to determine: (1) the nature of the original sedimentary and/or volcanic material of the fold belts; (2) the conditions of metamorphism(metamorphic facies); (3) the time of metamorphism and of volcanism and sedimentation; and (4) the stratigraphy of the metamorphic rocks. The intrusive rocks and their relationships to the metamorphic rocks are also studied as is the structural geology and various metasomatized and migmatitic rocks. A regional correlation is attempted.

Methods Used and Their Limitations

Field mapping of the Needle Falls Area has been followed by a petrographic study, chemical analyses, and K-Ar and Rb-Sr radiometric dating. During mapping,

Chapter I

INTRODUCTION

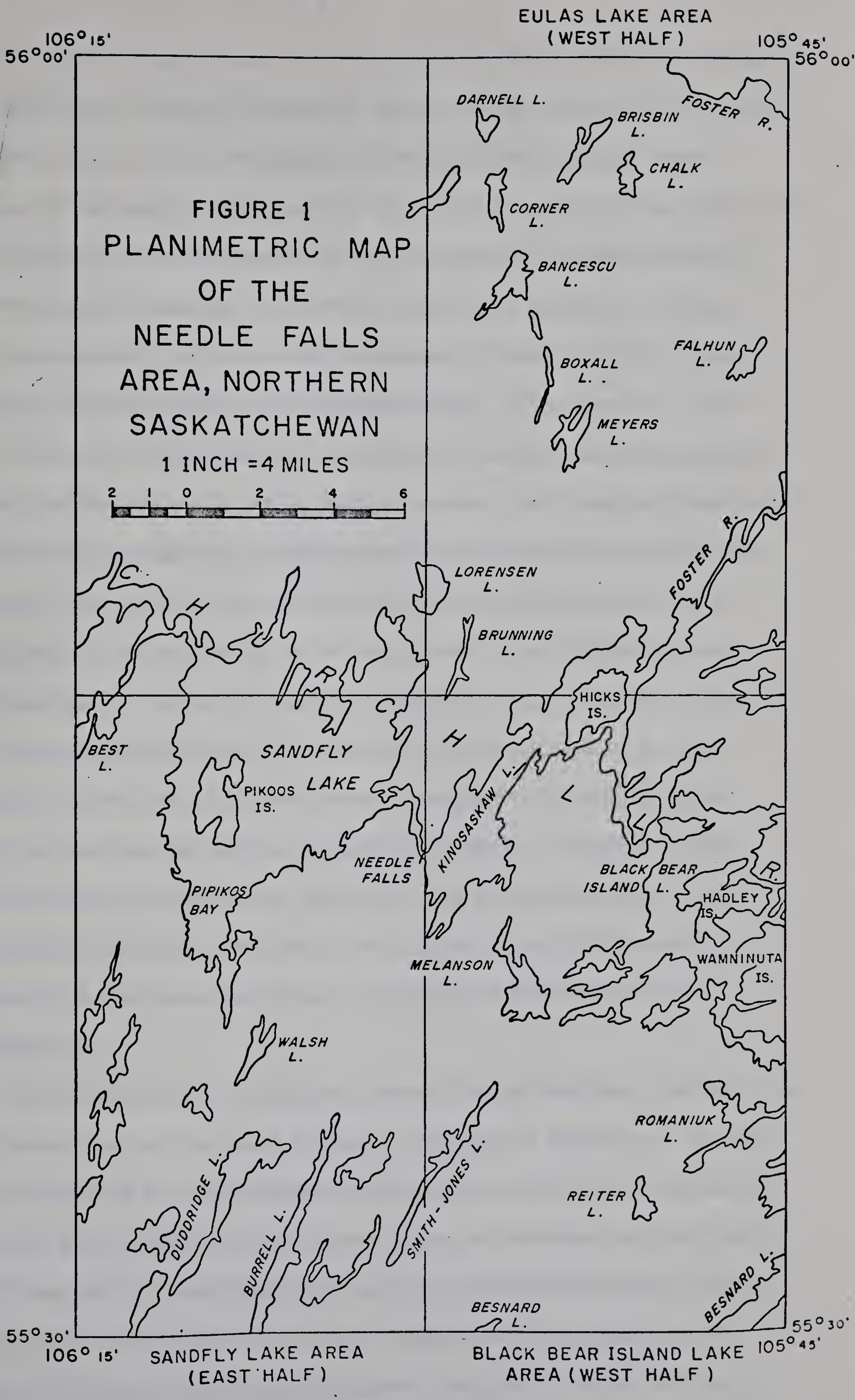
General Statement

The Amisk Lake Area (West Half), which is part of the [illegible] area (see Figure 1), was mapped by the writer in [illegible] for the Saskatchewan Department of Mineral Resources at a scale of one inch to one mile. The area was previously mapped [illegible] at the one inch to four mile scale [illegible]. [illegible] the presence of abundant volcanic rocks. A secondary consideration was a regional [illegible] to [illegible] the central part of the [illegible] belt and [illegible] along [illegible] have been studied [illegible]. During the course of the mapping it became evident that the [illegible] were not [illegible] but the geology was sufficiently [illegible] carried out in 1962 (Amisk Lake Area, East Half) and in 1963 ([illegible] Lake Area, West Half).

The Amisk Lake area is underlain by a variety of intrusive and metamorphosed rocks. The metamorphic rocks occur in two main belts of different orientation. This thesis is primarily a study of the metamorphic rocks and is concerned with determining: (1) the nature of the original sedimentary and/or volcanic material of the rocks; (2) the conditions of metamorphism [illegible]; (3) the time of metamorphism and of volcanism and sedimentation; and (4) the [illegible] of the metamorphic rocks. The intrusive rocks and their relationships to the metamorphic rocks are also considered as is the structural geology and various metamorphic and igneous [illegible]. A regional correlation is proposed.

Methods Used and Their Limitations

Field mapping of the Amisk Lake Area has been followed by a petrographic study, chemical analyses, and K-Ar and Rb-Sr radiometric dating. During mapping


EULAS LAKE AREA
(WEST HALF)
106° 15'
56° 00'
105° 45'
56° 00'
FIGURE 1
PLANIMETRIC MAP
OF THE
NEEDLE FALLS
AREA, NORTHERN
SASKATCHEWAN
1 INCH = 4 MILES
2 1 0 2 4 6
DARNELL L.
BRISBIN L.
FOSTER R.
CHALK L.
CORNER L.
BANCESCU L.
FALHUN L.
BOXALL L.
MEYERS L.
FOSTER R.
LORENSEN L.
BRUNNING L.
C H U R C H I L L
HICKS IS.
BEST L.
SANDFLY LAKE
PIKOOS IS.
KINOSASKAW L.
NEEDLE FALLS
BLACK ISLAND
BEAR L.
R.
HADLEY IS.
PIPIKOS BAY
MELANSON L.
WAMNINUTA IS.
WALSH L.
ROMANIUK L.
DUDDRIDGE L.
BURRELL L.
SMITH - JONES L.
REITER L.
BESNARD L.
BESNARD L.
55° 30'
106° 15'
55° 30'
105° 45'
SANDFLY LAKE AREA
(EAST HALF)
BLACK BEAR ISLAND LAKE
AREA (WEST HALF)

pace and compass traverses were run at intervals of 1,000 to 3,500 feet and the shorelines of major lakes were examined. Vertical aerial photographs at a scale of one inch to one mile and enlargements of these provided mapping control. The nature of the mapping imposes certain limits on further study of the area in this thesis. Although not reconnaissance (1 inch to 4 mile) it is regional mapping rather than detailed mapping. In addition, it was rarely possible to visit any outcrop twice as each year a new area was mapped. Further limits are imposed on the thesis by features common in the Canadian Shield. These include: lack or rarity of distinctive marker horizons and of primary features permitting top determinations; and the rarity with which contacts are seen. As a result of these factors: (1) the stratigraphic positions of samples used in subsequent work were generally not known at the time they were collected; and (2) map units were set up to include rocks of similar lithology which may include rocks of different stratigraphic positions. It is scarcely possible, given this type of sampling, to deal with lithological variations within a map unit which are related to its internal stratigraphy. Some idea of the total range of composition of each rock type within a map unit may be obtained by study of the samples collected. Gross lateral variations in mineralogical composition due either to variation in metamorphic grade or chemical composition may also be discernible and selection of samples for further petrographic work was made with this factor in mind (see Appendix I).

The petrographic work includes a number of modal analyses. The analytical limitations of these and choice of samples are discussed in Appendix I. The main problem concerning the modal analyses is that most rock units are of metamorphic rocks which are inhomogeneous on a regional scale, in individual outcrops, and in some cases within a hand specimen or even an individual thin section. It is possible, by cutting enough thin sections, to determine the composition of a uniform hand specimen to any required degree of accuracy. In the rocks being

dealt with, accurate determination of the composition of a single hand specimen was not considered to be of critical importance. Instead an attempt has been made to roughly determine the range of composition for each major rock type.

Chemical analysis was carried out mainly by X-ray fluorescence techniques. The analytical limitations of these techniques are discussed in Appendix II. The problem of choice of samples for analysis is discussed in Appendix I. Major problems are the choice of representative samples for analysis and (in the interpretation of the data) the problem of metasomatism.

Radiometric dating carried out includes K-Ar dating of mineral separates and Rb-Sr whole rock dating. The limitations of these techniques are partly analytical (see Appendices V and VI). The value of the techniques are further limited by the high-grade metamorphism which accompanied the Hudsonian orogeny and its blurring of the record of earlier events.

Location and accessibility of the thesis area

The Needle Falls Area, Saskatchewan, consists of the Eulas Lake (West Half), Sandfly Lake (East Half) and Black Bear Island Lake (West Half) map-areas. These are shown on Figure 1. Each of the three areas covers about 170 square miles. Their mutual junction (55° 45' N, 106° 00' W) is approximately 53 miles northwest of the village of La Ronge. The northwest part of the Sandfly Lake Area (East Half) is approximately 30 miles by water from the settlement of Pinehouse on Snake Lake. Location maps accompany Figures 16 and 17 (in pocket).

Most of the Black Bear Island Lake Area (West Half), the Sandfly Lake Area (East Half), and the southeast and southwest corners of the Eulas Lake Area (West Half), are readily accessible from Churchill River or Foster River, or from numerous lakes which are connected by portages to the Churchill River system (Figure 1). The rest of the Eulas Lake Area (West Half) is not as readily

accessible, but all of it may be reached from one or another of a number of lakes upon which float-equipped aircraft may land.

In summer, access to the area is easiest by float-equipped aircraft from La Ronge. It may also be reached by canoe route from Nemeiben Lake, via a series of small lakes to Besnard Lake, and thence to Black Bear Island Lake via Hallowell Lake and several small lakes. A second canoe route is west along the Churchill River from Otter Rapids, which may be reached from the all weather highway that has been constructed for 54 miles north of La Ronge. Both routes involve numerous portages.

In the northern two-thirds of the Eulas Lake Area (West Half) bush travel is generally difficult due to a tangle of deadfall, young jack pine and minor black spruce, the result of a fire or fires more than 30 years ago. The northern two-thirds of the other two areas and the southern third of the Eulas Lake Area (West Half) appear to have been burned over at about the same time, but much of the deadfall has rotted making travel easier. Birch and poplar are common in this region. The southern third of the Black Bear Island Lake Area (West Half) and the Sandfly Lake Area (East Half) is covered by a mature forest of mixed black spruce, birch, poplar, and locally, jack pine. There are local areas of burn in the former area, particularly along the Churchill River on Wamninuta Island and further south, in which it is very difficult to travel.

Physiography of the thesis area

The thesis area is one of low to moderate relief with few ridges and hills reaching more than 200 feet above the level of the nearest large lake. Maximum local relief is approximately 350 feet. Throughout most of the area lakes and ridges are generally elongate and trend north-northeast. This trend is subparallel to both the direction of glacial movement and of foliation in the bedrock. In the eastern and southern part of the Black Bear Island Lake Area

(West Half) several diverse trends are present (see Figure 17). In the Eulas Lake Area (West Half) the transverse north-northwest trend of the chain of lakes from Meyers Lake to Darnell Lake and similar trends elsewhere are believed to be controlled by fault zones (Figures 1, 16).

The topography of the area has been modified by glaciation, although its main features appear to be reflections of bedrock structure. Glacial drift is widespread as a thin veneer. Outwash plains, consisting mainly of sand or silt, with a few pebbles, are abundant in a belt extending from the northeast corner of the Eulas Lake Area (West Half) to the north tip of Walsh Lake in the Sandfly Lake Area (East Half). Much of the region south of Walsh Lake is covered by gently undulating moraine consisting in large part of boulders and cobbles. Numerous kettle holes occur locally in this region. No eskers were noted in the area.

All streams in the area drain into the Churchill River, most of them directly, but some via Foster River, Bělanger River, or Besnard Lake.

Previous work

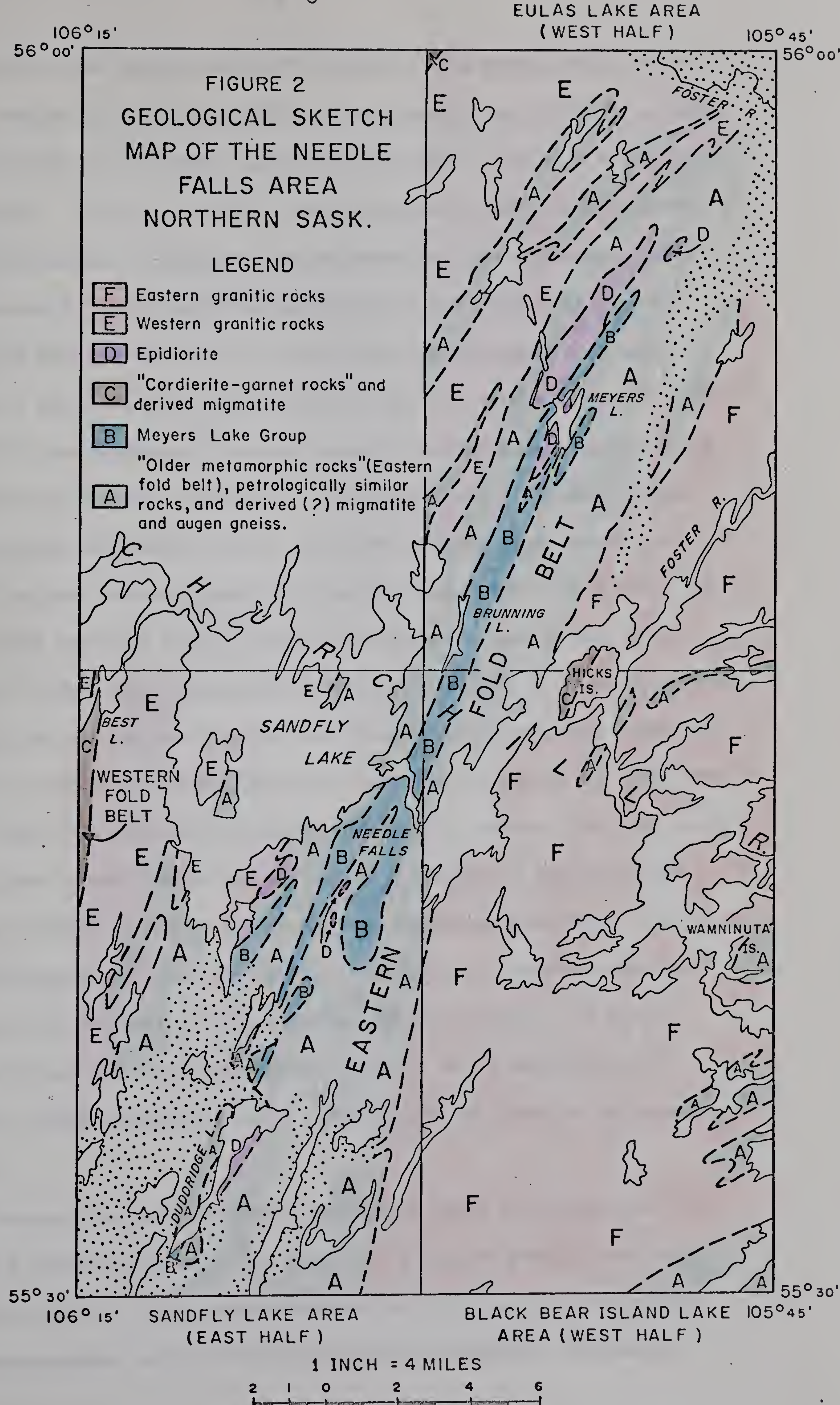
The first work in the area was performed by Sir John Richardson, who was attached to Sir John Franklin's Arctic expeditions of 1819 to 1822 (Franklin, 1823). He described general geological features and rock types observed during a trip from The Pas, Manitoba, to Ile-a-la-Crosse via the Churchill River. The next work was done by Tyrrell in 1892 (Selwyn, 1895; Tyrrell and Dowling, 1896). He mapped the geology along the Foster and Churchill Rivers in the course of a reconnaissance survey along the route from Lake Athabasca to Prince Albert via Wollaston Lake, Geikie River, the Foster Lakes, Foster River, and the Churchill River. In 1913 McInnes compiled a memoir on the basins of the Nelson and Churchill Rivers in which he summarized all available geological knowledge. The Lac La Ronge Sheet (West Half), of which the Eulas Lake Area (West Half) and the Black Bear Island Lake Area (West Half) are a part, was mapped by

McLarty (1936a) at a scale of one inch to four miles. The Foster Lake Sheet (West Half), immediately north of the Lac La Ronge Sheet (West Half), was mapped by McMurchy (1938b). The Ile-a-la-Crosse map-area, which includes the Sandfly Lake Area (East Half), was mapped by Frarey (1950). Airborne magnetometer and electromagnetic surveys of the Eulas Lake Area (West Half), carried out for the Saskatchewan Department of Mineral Resources, were published in 1958 as maps at the scale of one inch to one half mile. The Black Bear Island Lake Area (East Half) was mapped by A. Morris (1965) during the summer of 1963.

General Geology

The areal distributions of major subdivisions of the rocks of the Needle Falls area are shown on Figure 2, and of the various map-units on Figures 16 and 17. A stratigraphic column, based on all available evidence, is given in Table I. Discrepancies between the stratigraphic column in Table I and the map column (Figures 16 and 17) are discussed in the following pages. These are partly due to the fact that the map legend was drawn up for the purposes of a Saskatchewan Department of Mineral Resources Report late in 1963, prior to the completion of laboratory work (1964-65) and a full consideration of the evidence concerning stratigraphic relations. They also occur partly because in such departmental reports it has been customary to group rocks of similar lithology into a single map-unit in the absence of positive evidence that they are of greatly different stratigraphic position. In the stratigraphic column which appears as Table I, rocks of similar lithology which may occur in different stratigraphic positions are distinguished.

As shown on Figures 2, 16 and 17, the metamorphic rocks form one large fold belt and a number of smaller, parallel belts which extend across the thesis area in a north-northeasterly direction. The largest belt is referred to through-


EULAS LAKE AREA
(WEST HALF)
106° 15'
56° 00'
105° 45'
56° 00'
FIGURE 2
GEOLOGICAL SKETCH
MAP OF THE NEEDLE
FALLS AREA
NORTHERN SASK.
LEGEND
F Eastern granitic rocks
E Western granitic rocks
D Epidiorite
C "Cordierite-garnet rocks" and derived migmatite
B Meyers Lake Group
A "Older metamorphic rocks" (Eastern fold belt), petrologically similar rocks, and derived (?) migmatite and augen gneiss.
FOSTER R.
MEYERS L.
BRUNNING L.
HICKS IS.
FOSTER R.
CHURCHILL R.
BEST L.
SANDFLY LAKE
WESTERN FOLD BELT
NEEDLE FALLS
EASTERN FOLD BELT
WAMNINUTA IS.
DUDDRIDGE L.
55° 30'
106° 15'
55° 30'
105° 45'
SANDFLY LAKE AREA
(EAST HALF)
BLACK BEAR ISLAND LAKE
AREA (WEST HALF)
1 INCH = 4 MILES
2 1 0 2 4 6

out this thesis as the "eastern fold belt" (Figure 2). The eastern margin of the parallel "western fold belt" crops out in the northwest corners of the Eulas Lake Area (West Half) and the Sandfly Lake Area (East Half). Most of it is outside of the thesis area. As shown in Table I, the metamorphic rocks have been divided into six main divisions. These are: the metasomatized and migmatized rocks (mainly map-unit 11), the metamorphosed intrusive rocks (map-unit 10), the Meyers Lake Group (map-units 7, 8, and 9), the "older metamorphic rocks" (map-units 1 and 4 and part of map-units 2 and 3), the "cordierite-garnet rocks" (map-unit 5), and metamorphic rocks of uncertain relationships (map-unit 6 and part of map-units 2 and 3). Map-unit 11 (see Figures 16, 17) is derived from most of the other metamorphic rocks. The relative stratigraphic positions and nature of the other metamorphosed rocks are clear from Table I. It will be noted, however, that map-units 2, 3b, 5 and 6 are numbered at least in part out of sequence. In the cases of map-unites 2 and 3b, all rocks in the thesis area which appeared to be lithologically similar were grouped in the same units. Some of these rocks occur in the eastern fold belt, where they are part of the "older metamorphic rocks" and have a fairly definite stratigraphic position. Rocks of similar lithology from outside this belt are not definitely correlative with the "older metamorphic rocks" and hence are of uncertain stratigraphic position. The rocks comprising map-units 5 and 6 were so numbered because it was felt originally that map-unit 6, like map-unit 5, might be a part of the group "cordierite-garnet rocks" and that the "cordierite-garnet rocks" might conformably (?) overlie the "older metamorphic rocks". Both possibilities are now regarded as uncertain.

The intrusive rocks are briefly described in Table I and their areal distribution is shown on Figures 2, 16, and 17. The western granitic rocks call for further comment. These were numbered as unit 12, i.e. as a unit younger than the metamorphic rocks, on the basis of field relationships. Subsequent

Table I: Table of Formations

	Name	Description
Recent and Pleistocene		Till, gravel, sand, silt, clay, peat
	UNCONFORMITY	
Precambrian		Vein quartz (Map unit 15)
	INTRUSIVE CONTACTS	
		Pegmatite (Map unit 14). Perhaps in part younger than unit 15 or older than unit 13
	INTRUSIVE CONTACTS	
	Eastern granitic rocks	Equigranular quartz monzonite to biotite quartz diorite, porphyritic or porphyroblastic granodiorite. (Map unit 13)
	INTRUSIVE CONTACTS	
		Hornblende quartz diorite[1]
	INTRUSIVE CONTACTS (?)	
	Metasomatized and migmatized rocks	Porphyroblastic potassium feldspar gneiss, augen gneiss, migmatite, and granitic gneiss (Map unit 11)
		RELATIONSHIP UNCERTAIN
		Anthophyllite-cordierite-biotite gneiss[2]
	GRADATIONAL CONTACTS	

Table I: Table of Formations (Cont'd.)

Metamorphosed intrusive rocks	Epidiorite (Map unit 10)
INTRUSIVE CONTACTS (?)	
Meyers Lake Group	Quartzite, feldspathic quartzite, calcareous quartzite, minor quartz pebble meta-conglomerate (Map unit 8); biotite-muscovite-quartz schist and gneiss (Map unit 9). Interlayered
	CONFORMABLE CONTACT
	Quartz pebble meta-conglomerate, minor interlayered quartzites and biotite-muscovite-quartz schist and gneiss. Some meta-arkose? (Map unit 7)
UNCONFORMITY (?)	
"Older metamorphic rocks"	Meta-arkose (Map unit 1); hornblende-biotite gneiss and granulite and amphibolite (part of Map unit 2): knobby biotite-plagioclase gneiss (Map sub-unit 3a); biotite schist and gneiss (part of Map sub-unit 3b); acidic metavolcanic (?) rocks (Map unit 4); mutual relationships in part uncertain but in part interlayered
RELATIONSHIP TO OTHER METAMORPHIC ROCKS UNCERTAIN	
"Cordierite-garnet rocks"	Biotite-cordierite-sillimanite schist, gneiss, and granulite, with or without garnet, biotite-garnet schist, gneiss, and granulite, with or without sillimanite, plagioclase-scapolite-clinopyroxene rocks, hornblende-biotite-clinopyroxene rocks (all Map unit 5)
UNCONFORMITY (?)	

Table I: Table of Formations (Cont'd.)

	Western granitic rocks	Equigranular, mainly pink, mainly quartz monzonite but probably ranging from granite to monzonite. (Map unit 12, some gneissic varieties probably included in Map unit 11)
	RELATIONSHIPS TO OTHER ROCKS UNCERTAIN; PROBABLY ALL OLDER THAN EASTERN GRANITIC ROCKS, MAY BE AT LEAST IN PART OLDER THAN THE WESTERN GRANITIC ROCKS	
		Hypersthene amphibolite (Map sub-unit 6a), clinopyroxene amphibolite (Map sub-unit 6b), amphibolite and hornblende-biotite gneiss and granulite (part of Map unit 2), biotite gneiss and schist (part of Map sub-unit 3b)

[1] Does not form a mappable unit.
[2] Probably derived by metasomatism from knobby biotite-plagioclase gneiss (Map sub-unit 3a).

work suggests that they are actually older than most or all of the metamorphic rocks and have in whole or in part been re-mobilized.

The metamorphic rocks of the eastern fold belt are isoclinally or almost isoclinally folded. The folds plunge at low angles and the limbs dip steeply to vertically. Isoclinal folding is probably also present in the minor fold belts and the western fold belt. Several faults and shear zones were noted in the thesis area. They belong to two sets; longitudinal faults and shear zones, and north- to northwest-trending transverse faults.

Chapter II

GENERAL DESCRIPTION OF THE METAMORPHIC ROCKS

Introduction

This chapter gives general descriptions of the metamorphic rocks and discusses the relationships of the rock-types within each major group. A discussion of the relationships of the various groups is deferred to Chapter VIII. Mineralogical descriptions, photographs, and analyses appear in Appendices IX, X, and XI respectively. Sample locations are tabulated in Appendix VII and samples are grouped by map unit in Appendix VIII. All "units" referred to in this and following chapters are map-units unless clearly stated otherwise. As the rocks described are high grade metamorphic rocks and have been recrystallized, grain sizes are classified according to the igneous scale and not the sedimentary scale. "Fine-grained" rocks have a grain size of less than 1 mm; "medium-grained" rocks of 1 to 5 mm; "coarse-grained" rocks of 5 to 30 mm, and "very coarse-grained" rocks of more than 30 mm.

"Older Metamorphic Rocks" and Petrologically Similar Rocks

INTRODUCTION

The "older metamorphic rocks" comprise map-units (1) and (4) and the rocks belonging to map-units (2) and (3) which occur within the eastern fold belt (see Figures 16, 17). Rocks belonging to map-units (2) and (3) which occur outside of the eastern fold belt are similar lithologically to rocks included in these map-units which occur within the belt and have been grouped with them for descriptive purposes, although they are not necessarily of the same age.

In the following sections the rock types comprising each map-unit are listed, type locations are given, and their mutual relationships and the relat-

ionships of the map-unit to other map-units are discussed. This is followed by a description of the predominant rock type within each map-unit. Minor rock types within each map-unit are commonly predominant in another unit and are described only as part of the description of the latter unit.

MAP-UNIT (1)

Introduction

Map-unit (1) consists predominantly of meta-arkose[1], with minor amphibolite, hornblende-biotite and biotite rocks. The largest body of unit (1) in the area occurs east of Walsh Lake and west of Duddridge Lake, Sandfly Lake Area. This body is readily accessible and the meta-arkose within it can be considered to be the "type" example. This body and a similar large body east of Lorensen Lake, Eulas Lake Area, are interpreted as forming the cores of anticlines (see Chapter VII). If this interpretation is correct the body of unit (1) east of Lorensen Lake is older than at least part of map-units (2) and (3a) and the other body is older than at least part of map-units (3a) and (3b). However, the outcrop pattern near the south arm of Boxall Lake, Eulas Lake Area (55°52'N, 105°55'W) suggests large scale interlayering of units (1) and (2) and hence indicates that the rocks grouped in unit (1) are in part contemporaneous with the rocks grouped in unit (2). This is also suggested by the presence of a number of apparent elongate lenses of unit (1) within unit (2) in the northern half of the Eulas Lake Area.

Arkosic rocks up to 30 feet thick which locally underlie the quartz-pebble meta-conglomerate belonging to the Meyers Lake Group have been included in unit (1). The stratigraphic position of these rocks is uncertain and

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[1] The "meta-arkose" belonging to the "older metamorphic rocks" is perhaps better described as "meta-arkosic-wacke" (see Chapter IV) or quartz- K feldspar-muscovite gneiss. However, when Figures 16 and 17 were printed (at an early stage of this investigation) this rock-type was referred to as "meta-arkose" and this usage has been retained in the thesis so that the text will conform with the figures.

they may actually be a "granite wash" or re-worked meta-arkose which belongs to and forms the base of the Meyers Lake Group locally. The type example occurs on the east shore of Meyers Lake at 55°51'10"N, 105°53'28"W. Similar rocks occur at the southeast corner of the southwest bay of Meyers Lake.

Within unit (1) the meta-arkose has been observed in direct contact only with segregation (?) pegmatite, biotite gneiss, and hornblende-biotite rocks or amphibolite. The pegmatite occurs as small, concordant pods (see Chapter III) in a number of places. Biotite gneiss, in the only place where contacts were seen (55°32'15"N, 106°09'55"W), occurs in discrete beds up to ten feet wide interlayered with the meta-arkose. Biotite gneiss is estimated to form no more than ten per cent of this outcrop. It is rare within map-unit (1). The only hornblende-biotite rock or amphibolite found in contact with meta-arkose is shown in Plate I, 2. This is either a lens or stretched cobble. The rocks forming unit (1) have not been observed in contact with the rocks forming any unit other than those mentioned above except for intrusive bodies of pegmatite.

Of the rock types which form unit (1), only the predominant meta-arkose is described in the following section. The hornblende-biotite rocks and amphibolite and the biotite gneiss are similar to those described in the discussions of map units (2) and (3b) respectively.

Meta-arkose

Selected thin sections of meta-arkose from the main bodies of unit (1) contain 40 to 47 per cent quartz, 12 to 21 per cent potassium feldspar, 3 to 9 per cent plagioclase (sodic oligoclase to sodic andesine), less than one per cent biotite, 30 to 37 per cent muscovite, and a trace[1] to 2 per cent opaque minerals. Selected thin sections of the meta-arkose immediately underlying the Meyers Lake Group contain 37 to 49 per cent quartz, 18 to 31 per cent potassium feldspar, a trace to 10 per cent plagioclase (sodic oligoclase to calcic oligoclase), nil to 1 per cent biotite, 21 to 35 per cent muscovite, and a trace of

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[1] In Chapters II and III a "trace" is 0.7 per cent or less

opaque minerals. Accessory minerals occurring in meta-arkose both from the main bodies and from below the Meyers Lake Group include apatite, zircon, and sphene. Other minerals which occur locally include garnet, sillimanite, and tourmaline. Plagioclase is lightly sericitized on some thin sections and biotite is partly altered to chlorite in one thin section. Garnet was seen only in the meta-arkose body south of Lorensen Lake, Eulas Lake Area. Sillimanite is confined to the body of meta-arkose on the east shore of Sandfly Lake east-southeast of the southeast tip of Pikoos Island. Tourmaline was noted in one thin section from the meta-arkose on the west side of Duddridge Lake, Sandfly Lake Area.

Meta-arkose is massive, schistose, or gneissic. The grain size[1] in ungranulated sections is usually 0.2 to 0.6 mm (maximum diameter). The meta-arkose is generally pink on the fresh and weathered surfaces but locally it is pale or medium gray. Weak colour-layering, either in shades of pink or grey and pink, occurs locally. This may or may not be accompanied by a slabby fracture parallel to the layering. The layers are one-quarter inch to about six inches thick. The sillimanite-bearing meta-arkose which occurs east-southeast of Pikoos Island is crowded with disc-shaped quartz-muscovite-fibrolite (sillimanite) segregations (Plate 1,3), generally two to three inches in diameter and about one half inch thick. These were not noted elsewhere.

Sparse pebbles, cobbles and boulders (Plate I, 1) were noted in: (1) the meta-arkose body that extends from the southwest corner of the Eulas Lake Area into the northeast corner of the Sandfly Lake Area; (2) the meta-arkose west of Duddridge Lake and its continuation to the north-northeast; and (3) the meta-arkose south of Lorensen Lake. Where the pebles, cobbles,

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[1] All grain sizes reported in this thesis that have been determined in thin section are the largest diameter of the apparently largest grains in the thin section in question, disregarding grains which are obviously atypical (e.g. the large quartz grains in Plate II,8). This assumes that the rock is equigranular and, as must be the case, that the diameter of most grains in the plane of the thin section is less than their true maximum diameter.

and boulders are comparatively common (two or more per 10 square feet of outcrop) the rock is mapped as pebbly meta-arkose and is included in sub-unit (1a). Most pebbles, cobbles, and boulders consist of fine to medium-grained, pink, non-foliate granitoid rocks. Some appear to be aplite (Plate I, 1). Many pebbles and cobbles are of massive, white to dark bluish-grey quartz. The largest granitoid boulder seen is about 18 inches in maximum diameter and 6 inches in minimum diameter. A few pebbles in the meta-arkose body which crosses the Eulas Lake Area - Sandfly Lake Area boundary have one elongate, sub-horizontal axis, but most of the pebbles and all cobbles and boulders seen in three dimensions only show flattening parallel to foliation. The ratio of shortest axis : longest axis generally ranges from about 1 : 2 to 1 : 12 in all outcrops.

About one-third of the thin sections of meta-arkose show some degree of granulation. The distribution of the granulated samples has no obvious relationship to known faults or shear zones. In strongly granulated rocks, rare quartz and feldspar grains and lenses of these grains are preserved in a mylonitic matrix. In ungranulated rocks the feldspars, quartz, and micas usually form a nearly equigranular mosaic. In most sections there is a sub-parallel alignment of mica (Plate II; 1-3, 5, 6) and this may be accompanied by an elongation of quartz and feldspar grains (Plate II, 1, 2, 5). Muscovite (Plate II, 1,2) and rarely potassium feldspar (Plate II, 3) may be concentrated in layers. Garnet occurs as small, rounded porphyroblasts, in many cases with opaque-clouded centres and clear rims (Plate II, 6). The foliation as defined by mica flakes is deflected around and transected by the garnets. Sillimanite (fibrolite) occurs as sheaves of needles between quartz grains, in places having plainly replaced muscovite, and as swarms of small needles of variable orientation within quartz-muscovite-fibrolite segregations (Plate II, 4). The opaque minerals in part occur in angular grains across the foliation (Plate II, 3) suggesting that they formed late.

Thin section examination of typical granitoid cobbles and boulders shows that they consist of a sutured, granulated, non-foliate mosaic of quartz and feldspar (Plate II, 7, 8) with occasional coarse flakes of muscovite. The average grain size in the thin sections examined is 0.2 to 0.5 mm but some fractured grains are as much as 5 mm (Plate II, 7). The range of composition of selected samples is 26 to 50 per cent quartz, 21 to 23 per cent potassium feldspar, 21 to 48 per cent plagioclase (sodic to intermediate oligoclase), 2 to 6 per cent muscovite, nil to 1 per cent biotite, and a trace to 1 per cent opaque minerals. The plagioclase is commonly slightly sericitized. Minor sphene is associated with muscovite. Other accessory minerals are apatite and zircon.

MAP-UNIT (2)

Introduction

Unit (2) consists predominantly of hornblende-biotite gneiss and granulite, with minor amphibolite, biotite gneiss and schist,and meta-arkose. Sub-unit (2a) consists predominantly of amphibolite with minor hornblende-biotite rocks. Other sub-units consist mainly of hornblende-biotite rocks with minor knobby biotite-plagioclase gneiss (2b) or subordinate acidic meta-volcanic (?) rocks (2c). The relationship of the hornblende-biotite rocks and amphibolite to the meta-arkose has been described in the preceding section. The hornblende-biotite rocks and amphibolite are interlayered with each other and with the other rock types forming the "older metamorphic rocks".

Interlayering with the knobby biotite-plagioclase gneiss was noted only between the south tip of Boxall Lake, Eulas Lake Area and the Churchill River just east of the rapids at the discharge of Sandfly Lake. The northern part of the Boxall Lake - Churchill River belt is predominantly hornblende-biotite rocks and is mapped as sub-unit (2b), while the southern half is predominantly knobby biotite-plagioclase gneiss and is mapped as sub-unit (3a). The interlayered rocks were not seen in contact with each other but appear to be conformable. Individual layers of both

the hornblende-biotite rocks and knobby biotite-plagioclase gneiss probably range from about 20 feet to as much as 200 feet in thickness. They are fairly well exposed at 55°50'52"N, 105°55'30"W.

Biotite gneiss and schist interlayered with the hornblende-biotite rocks is quite rare in the northeast part of the thesis area but becomes increasingly abundant although still minor to the southwest. The biotite gneiss and schist and hornblende-biotite rocks were not seen in contact. Individual layers appear to be conformable and are probably in the order of 20 to 200 feet thick. Relationships are not certain due to the difficulty of distinguishing between the biotite gneiss and the hornblende-biotite gneiss in the field. The interlayered rocks are fairly well exposed in the Sandfly Lake Area at 55°40'25"N, 106°04'40"W.

The acidic meta-volcanic (?) rocks are almost completely confined to one zone near the eastern side of the eastern fold belt. Hornblende-biotite rocks and amphibolite are interlayered with them throughout this zone. Where the acidic meta-volcanic (?) rocks predominate the belt is mapped as unit (4) and where hornblende-biotite rocks and amphibolite predominate it is mapped as sub-unit (2c). The individual layers of hornblende- biotite rocks, amphibolite and acidic meta-volcanic rocks are 1/2 inch to at least 30 feet wide and are generally traceable for the full length of the outcrop, i.e. up to several hundred feet. The interlayering can be seen in a number of places. The most easily accessible well exposed examples may be found east of Orr Lake (55°49'55"N, 105°53'15"W.)

The contact of the hornblende-biotite rocks and amphibolite and the rocks forming the Meyers Lake Group was not seen. A major part of the migmatite and augen gneiss (unit 11) of the thesis area is derived from the hornblende-biotite gneiss and amphibolite. All contacts are wholly gradational and hence their location on the accompanying maps (Figures 16 and 17) is arbitrary. The migmatite is shown in Plate XVIII. The examples shown in this plate are readily accessible from Sandfly Lake. Good examples of augen gneiss gradational to hornblende-

biotite rocks and amphibolite occur on the west shore of Darnell Lake at 55°58'18"N, 105°57'37"W.

The hornblende-biotite gneiss and amphibolite which occur within the eastern fold belt can be seen intruded by dykes and sills of the western granitic rocks (unit 12) at 55°39'45"N, 106°08'15"W and elsewhere on the east side of Pipikos Bay. The petrologically similar rocks outside of this belt commonly show similar relationships. An excellent example occurs on a small island in Sandfly Lake at 55°44'15"N, 106°07'41"W. Hornblende-biotite gneiss and amphibolite within the eastern fold belt which are intruded by the eastern granitic rocks may be seen on the south shore of the Churchill River at 55°41'37"N, 105°59'38"W. Hornblende-biotite gneiss occurring as inclusions in epidiorite is shown in Plate XIII, 1. This location is readily accessible.

Of the rock types forming unit (2), only the hornblende-biotite rocks and amphibolite are described below. The meta-arkose, knobby biotite-plagioclase gneiss, biotite gneiss and schist, and acidic meta-volcanic (?) rocks included in this unit do not appear to differ from the similar rocks included in units (1), (3a), (3b), and (4) respectively and described as parts of these units.

Hornblende-Biotite Gneiss and Granulite[1] and Amphibolite

Minerals visible in hand specimens of the hornblende-biotite rocks and amphibolite are hornblende, biotite, quartz, plagioclase, and a few specks of pyrite. Three typical hornblende-biotite rocks (614-24-12, 614-37-1, 624-55-3) from the eastern fold belt contain a trace to 13 per cent quartz, 44 to 53 per cent plagioclase (sodic to intermediate andesine), 9 to 16 per cent biotite, 23 to 35 per cent hornblende, a trace to 5 per cent epidote, nil to 2 per cent opaque minerals,

[1] The term granulite is used throughout this thesis for any metamorphic rock in which the constituent minerals form a non-foliate mosaic, except where the text makes it clear that it is used as the name of a metamorphic facies.

traces of apatite and sphene, and nil to a trace of allanite. A hornblende-biotite rocks (614-63-4) collected a few feet from meta-arkose belonging to unit (1) within the eastern fold belt contains 31 per cent quartz, 4 per cent potassium feldspar, 41 per cent plagioclase (intermediate andesine), 13 per cent biotite, 8 per cent hornblende, 4 per cent epidote, and traces of allanite, opaque minerals, apatite, and sphene. A hornblende-biotite rocks (624-21-5a) which occurs interlayered with the acidic meta-volcanic (?) rocks in the eastern fold belt contains 10 per cent quartz, 3 per cent potassium feldspar, 32 per cent plagioclase (sodic andesine), 34 per cent biotite, 15 per cent hornblende, 5 per cent epidote, and traces of opaque minerals and apatite. A hornblende-biotite rock (614-S3) from outside of the eastern fold belt contains 24 per cent quartz, 23 per cent potassium feldspar, 37 per cent plagioclase (sodic andesine), 9 per cent biotite, 7 per cent hornblende, and traces of chlorite, opaque minerals, apatite, sphene, and zircon. A typical amphibolite (614-36-5) from the eastern fold belt contains 2 per cent quartz, 32 per cent plagioclase (intermediate andesine), 10 per cent biotite, 51 per cent hornblende, 4 per cent epidote, and traces of opaque minerals, apatite, sphene and carbonate. An amphibolite (614-64-10) which occurs interlayered with the acidic meta-volcanic (?) rocks in the eastern fold belt contains less than one per cent quartz, 27 per cent plagioclase, 6 per cent biotite, 63 per cent hornblende, 2 per cent sphene, 1 per cent epidote, 1 per cent opaque minerals, and a trace of apatite. A very mafic amphibolite (624-67-9a) from outside of the eastern fold belt contains 9 per cent plagioclase (sodic andesine), one per cent biotite and chlorite, 89 per cent hornblende, and traces of quartz, epidote, opaque minerals, apatite, and sphene.
A clinopyroxene-bearing amphibolite (614-28-11) from outside of the eastern fold belt contains 3 per cent potassium feldspar, 30 per cent plagioclase (intermediate andesine), 8 per cent biotite, 53 per cent hornblende, 4 per cent clinopyroxene, and traces of quartz, allanite, apatite, and sphene. Clinopyroxene-bearing amphibolites were noted only outside of the eastern fold belt.

In all varieties of hornblende-biotite rocks and amphibolite plagioclase is commonly slightly sericitized. In a few thin sections biotite is partly altered to chlorite and in one section (Plate III, 7) hornblende is altered to an actinolitic amphibole near a quartz-calcite veinlet.

In both the hornblende-biotite rocks and amphibolite the texture varies from massive to moderately foliate. The hornblende-biotite rocks are almost invariably fine- to medium- grained and the amphibolite medium- to coarse-grained. The fresh surface is medium to dark greenish grey or green and the weathered surface dark greenish grey. The thickness of the weathered zone is 1/4 inch or less. Locally within the hornblende-biotite rocks and amphibolite layering of slightly more and slightly less mafic varieties is distinguishable. Individual layers, which range from about 1/2 inch to at least 50 feet in thickness, are generally traceable for the full length of outcrops, i.e. up to several hundred feet. Good examples of this layering may be seen at 55°50'52"N, 105°55'30"W.

In thin section, the constituent minerals are generally seen to be equigranular and to form a mosaic with smooth grain boundaries (Plate III). In some thin sections there is a strong sub-parallel alignment of biotite (Plate III, 1,2, 3, 4) and a weaker alignment of elongate hornblende and plagioclase grains. In other sections the mineral grains show little or no preferred orientation (Plate III, 7, 8). Hornblende-rich and plagioclase-quartz-rich layers are present in a few thin sections of the hornblende-biotite rocks (Plate III, 3, 4). Biotite, hornblende, clinopyroxene, epidote, plagioclase, potassium feldspar, apatite and zircon are generally subhedral. Quartz and opaque minerals are commonly anhedral. Sphene occurs as subhedral to anhedral grains and as rims on some grains of opaque minerals. Allanite commonly occurs as cores with rims of colourless epidote.

MAP SUB-UNIT (3a)

Introduction

Sub-unit (3a) consists predominantly of knobby biotite-plagioclase gneiss, with minor anthophyllite-cordierite-biotite gneiss and hornblende-biotite gneiss. The sub-unit occurs only within the eastern fold belt in the thesis area. The anthophyllite-cordierite-biotite gneiss was found only within the body of sub-unit (3a) which extends north-northeast for about 7 miles from the part of the Churchill River between Sandfly Lake and Kinosaskaw Lake. It is particularly common along the west margin of this body, but occurs locally throughout it. Nowhere was it seen in contact with the knobby biotite-plagioclase gneiss, so their relationship is uncertain. However, chemical data suggest that the anthophyllite-cordierite-biotite gneiss is a metasomatized knobby biotite-plagioclase gneiss. The relationship of the hornblende-biotite rocks and the knobby biotite-plagioclase gneiss has been discussed in the preceeding section. The knobby biotite-plagioclase gneiss has not been seen in contact with any other rock type. An excellent and readily accessible exposure of this rock type occurs on the south side of the discharge of Sandfly Lake immediately above the rapids.

Of the rock types comprising sub-unit (3a) only the knobby biotite-plagioclase gneiss is described below. The hornblende-biotite rocks are similar to those previously discussed (see Map-unit 2) and will not be further described. Description of the anthophyllite-cordierite-biotite gneiss is deferred to the section on "Metasomatized and Migmatitic Rocks" in this chapter.

Knobby biotite-plagioclase gneiss

Selected thin sections of knobby biotite-plagioclase gneiss contain 7 to 19 per cent quartz, nil to 10 per cent potassium feldspar (all thin sections except one contain less than one per cent), 47 to 54 per cent plagioclase (sodic oligoclase to sodic andesine), 27 to 34 per cent biotite, nil to 4 per cent hornblende, and traces of each of opaque minerals, apatite, and zircon. Minor chlorite, replacing

biotite, occurs in one thin section. The plagioclase is commonly slightly sericitized. The texture is markedly porphyroblastic. The porphyroblasts, which consist of plagioclase, are ovoid to almost rectangular and are generally 4 to 10 mm in diameter. They occur in part in contact with each other and in part separated and outlined by patches to continuous films of dark-brown biotite. The biotite weathers more readily than the plagioclase, giving rise to a knobby or pebbled surface with the plagioclase in relief. In thin section, the porphyroblasts are seen to have slightly ragged to smooth margins and a sprinkling of fine (0·1 mm or less) biotite flakes and larger inclusions of quartz, potassium feldspar, and hornblende. Rarely they have quartz-rich zones at two ends which have the appearance of being pressure shadow effects (Plate IV, 1, 2). Some of the porphyroblasts have been broken down in whole or in part to ovoid zones composed mainly of plagioclase 0.2 to 0.4 mm in diameter, with lesser amounts of quartz, biotite and potassium feldspar (Plate IV, 1,2). Potassium feldspar, where present, is in small grains enclosed within the plagioclase and interstitial to it. In most thin sections the biotite sheaves and clumps which separate the plagioclase porphyroblasts are sub-parallel but a thin section containing 4 per cent hornblende lacks foliation.

The matrix in which the porphyroblasts occur consists of a fine-grained (0.2 to 0.5 mm) aggregate of quartz, plagioclase, and biotite with flakes of coarser biotite (Plate IV, 1,2).

MAP SUB-UNIT (3b)

Introduction

Sub-unit (3b) consists predominantly of biotite gneiss and schist, with minor hornblende-biotite rocks locally. The relationship of these rock types has been previously described (see Map-unit 2, this chapter). The biotite gneiss and schist were not seen in contact with any other metamorphic rock type. Good exposures of them may be seen on Sandfly Lake at 55°40'40"N, 106°06'00"W. They are

also well exposed on Besnard Lake where they are the metamorphic component of a migmatite (Plate XVII). At least in part of the granitic component of this migmatite appears to be intrusive and to be related to the eastern granitic rocks. Good examples of biotite gneiss and schist which are intruded by the eastern granitic rocks occur at 55° 39'58"N, 105°49'10"W. Similar rocks within the eastern fold belt which are intruded by the western granitic rocks may be seen at 55°40'35"N, 106°06'33"W.

The hornblende-biotite rocks have been previously described (see Map-unit 2, this chapter) and hence only the biotite gneiss and schist will be described below.

Biotite gneiss and schist

A thin section of biotite gneiss (624-56-15) from the eastern fold belt contains 25 per cent quartz, 49 per cent plagioclase (sodic andesine),26 per cent biotite, and traces of apatite, opaque minerals, and sphene. Two thin sections from outside of this fold belt contain respectively 19 and 9 per cent quartz, 11 per cent and nil potassium feldspar, 54 and 53 per cent plagioclase (sodic and intermediate andesine), 16 and 36 per cent biotite, and a trace and 3 per cent hornblende. Both contain traces of apatite, zircon, and opaque minerals and one contains a trace of chlorite replacing biotite. Plagioclase is slightly sericitized in almost all thin sections of rocks from both within and out of the eastern fold belt.

The biotite gneiss and schist are generally fine-grained but are medium-grained locally. They are light grey to dark grey on the fresh surface. Rusty weathering is fairly common, especially in the migmatitic rocks near the east boundary of the Black Bear Island Lake Area (West Half). Gneissic layering is, in general, poorly developed or absent.

The constituent minerals generally form an equigranular mosaic with smooth grain boundaries (Plate IV, 3-8). The grain size ranges from about 0.6 to 1.0 mm. There is always a weak to moderately strong sub-parallel alignment of biotite flakes and a slight elongation of grains of the other minerals sub-parallel to the

biotite. Hornblende occurs in small grains and in large, spongy-looking, poikiloblastic grains with highly irregular margins. The mafic minerals are unevenly distributed and there are quartzo-feldspathic and quartzitic patches in some thin sections (Plate IV, 5, 6).

UNIT (4)

Introduction

Unit (4) is composed predominantly of acidic meta-volcanic (?) rocks, with lesser amounts of hornblende-biotite rocks and amphibolite. The relationships of these rock types have been previously described (see Map-unit 2, this chapter). The acidic meta-volcanic (?) rocks were not seen in contact with any other rocks except the granitic component of the migmatite derived from them. The acidic meta-volcanic (?) rocks, and hence unit (4), form a zone up to 3,200 feet wide near the eastern edge of the eastern fold belt. This zone is traceable from the northeast corner of the Eulas Lake Area (West Half) to about one mile southwest of Webb Lake in the Sandfly Lake Area, apart from two small "breaks" north and south of Needle Falls. The zone was originally continuous, as the rocks in these "breaks" are migmatite and augen gneiss (sub-unit 11b) derived from the acidic meta-volcanic (?) rocks. Locally within this zone the hornblende-biotite rocks are predominant and these localities are shown on the map (Figure 16) as sub-unit (2c). A single outcrop about one and one half miles west-southwest of Webb Lake suggests that the acidic meta-volcanic (?) rocks swing around the syncline west of Webb Lake (Figure 17). The only other occurrence is on the west shore of Burrell Lake in the southern part of the Sandfly Lake Area. Lack of identification of acidic meta-volcanic (?) rocks west of the main zone may be due to their alteration to migmatite and augen gneiss, but they are so distinctive they should be recognizable if present. It seems probable therefore that they either lens out to the west or have not been exposed by folding. Good examples of the acidic meta-volcanic (?) rocks (see Plate V, 1) and their migmatitic equivalent may

be seen on the east and west ends respectively of the portage around Needle Falls (55°41'34"N, 105°59'35"W). Augen and porphyroblastic gneiss derived from the acidic meta-volcanic rocks are well exposed at 55°41'10"N, 105°59'45"W.

Of the rock types comprising unit (4), only the acidic meta-volcanic (?) rocks are described below. The hornblende-biotite gneiss and amphibolite are similar to those described as forming most of unit (2).

<u>Acidic meta-volcanic (?) rocks</u>

Selected thin sections of the acidic meta-volcanic (?) rocks contain 10 to 30 per cent quartz, 14 to 42 per cent potassium feldspar, 21 to 41 per cent plagioclase (intermediate oligoclase to intermediate andesine), 5 to 36 per cent biotite, nil to 3 per cent hornblende, and less than 1 to nearly 2 per cent opaque minerals. Other minerals which occur in traces in one or more thin sections include chlorite (replacing biotite), apatite, zircon, sphene, epidote, allanite, and a carbonate. Very minor sericite (replacing plagioclase) is widespread. One thin section contains 4 per cent sericite.

The acidic meta-volcanic (?) rocks are in part massive and in part layered (Plate V, 1). The layers are generally 1/4 inch to 1/10 inch wide, although exceptionally they are up to 1 inch in width. Individual layers have been traced for as much as 30 feet. On the fresh surface, the layers are slightly different shades of pale gray and may be just discernible. On the weathered surface, however, some layers are pale grey or chalky white whereas others have a rusty-red colour, so that the layering is greatly accentuated. The weathered zone is generally paper thin but may be as much as 1/4 inch thick. This rock type is characterized by extremely close jointing (in places the spacing of joints is 1/2 inch or less) and a very brittle, locally almost conchoidal, fracture. It is generally equigranular and aphanitic, although euhedral to ovoid plagioclase and potassium feldspar porphyroblasts as much as 1/2 inch in diameter occur along both margins of the

main zone. They are particularly common along its eastern margin and here this unit is altered in part to augen and porphyroblastic gneiss.

In thin section a sub-parallel alignment of biotite flakes and elongate grains of quartz, potassium feldspar, plagioclase, and most of the other minerals (Plate V, 4) is generally seen but some thin sections lack this alignment (Plate V, 5). The constituent minerals generally form an equigranular mosaic with an average grain size of 0.1 to 0.2 mm. Porphyroblastic potassium feldspar and plagioclase are present in several thin sections, and one contains small lenses of coarser quartz. A weak layering, due to alternation of biotite-rich and biotite-poor layers, is present in several thin sections (Plate V, 2). Granulation is common (Plate V,5) and in some thin sections the constituent minerals form ovoid grains surrounded by a fine granular aggregate derived from them. Parallel trains of very fine biotite, accompanied by muscovite and carbonate in one thin section, were noted in most granulated rocks. The granulation has no obvious relationship to known faults or shear zones.

Rock of Uncertain Stratigraphic Position

INTRODUCTION

The metamorphic rocks discussed in this section include only map-units (5) and (6), both of which are not found in the eastern fold belt. Metamorphic rocks which occur outside of this belt and are petrologically similar to rocks which occur within the belt have been discussed previously as parts of map-units (2) and (3). Such rocks, where occurring outside the eastern fold belt, are of uncertain stratigraphic position.

MAP-UNIT (5)

Introduction

This unit consists predominantly of biotite-cordierite-sillimanite-(garnet)[1]

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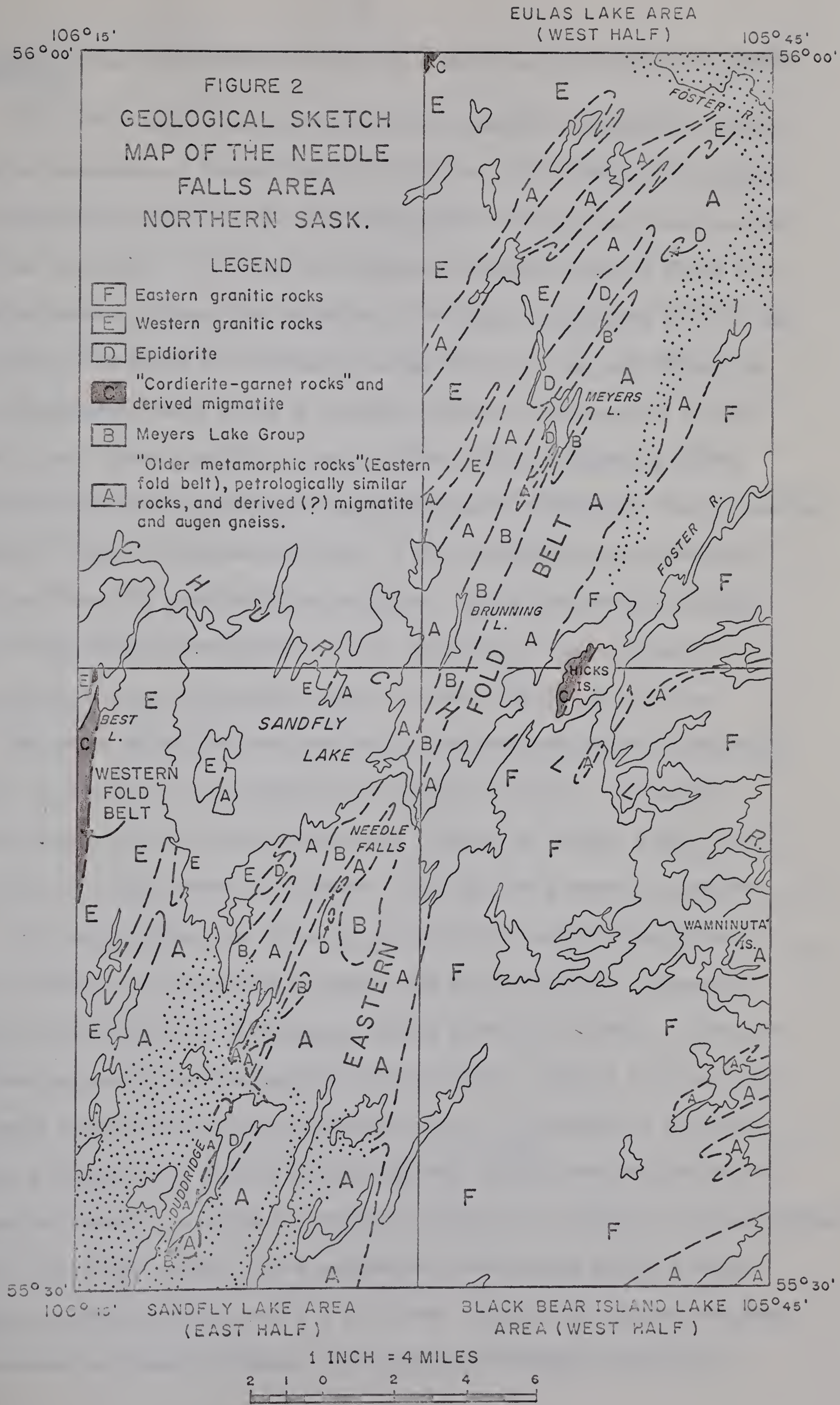
[1] brackets indicate that a mineral is present in the rock type in places and absent elsewhere.

and biotite-garnet-(sillimanite) schist, gneiss and granulite. It also contains minor biotite-poor ("arkosic") rocks, plagioclase-scapolite-clinopyroxene rocks, and hornblende-biotite-clinopyroxene rocks. Unit (5) and migmatite derived from it (sub-unit 11d) are the only units belonging to the "cordierite-garnet rocks" which occur in the thesis area (see Figure 2, following page). The "arkosic" rocks show large scale interlayering with cordierite- and biotite-rich rocks. Individual layers range from about 6 inches to tens of feet in width. The plagioclase-scapolite-clinopyroxene rocks and hornblende-biotite-clinopyroxene rocks have not been observed in contact with each other or the other rocks forming unit (5). However, all of these rock types are believed to be interlayered. Pegmatitic pods, as much as a few feet long and a foot wide, are present in biotite-rich cordieritic rocks but are rare. They consist mainly of quartz and feldspars but contain minor cordierite, garnet and biotite. The cordieritic and/or garnetiferous rocks, including biotite-poor ("arkosic") rocks, are readily accessible and well exposed on the shores of Best Lake in the northwest corner of the Sandfly Lake Area (East Half). The plagioclase-scapolite-clinopyroxene and hornblende-biotite-clinopyroxene rocks can be seen at 55°41'51"N, 105°53'38"W and 55°45'04"N, 105°53'37"W respectively.

The largest bodies of unit (5) in the thesis area occur in the northwest corner of the Eulas Lake Area (West Half) and of the Sandfly Lake Area (East Half), where they form the eastern fringe of the western fold belt. Rocks of similar composition occur on strike southwest of and between these occurrences (Frarey, 1950, p. 5). These rock types also form scarce, small, mappable inclusions in the granitic rocks east of the eastern fold belt, and occur as rare inclusions in the granitic rocks of unit (12) west of Sandfly Lake. Examples of the former may be seen at 55°43'38"N, 105°53'48"W and the latter at 55°42'10"N, 106°13'15"W. The two predominant rock types are associated throughout the thesis area except in migmatites near Romaniuk Lake, Black Bear Island Lake Area, where the biotite-garnet-(sillimanite) rocks occur alone.


EULAS LAKE AREA
(WEST HALF)
106° 15'
56° 00'
105° 45'
56° 00'
FIGURE 2
GEOLOGICAL SKETCH
MAP OF THE NEEDLE
FALLS AREA
NORTHERN SASK.
LEGEND
F Eastern granitic rocks
E Western granitic rocks
D Epidiorite
C "Cordierite-garnet rocks" and derived migmatite
B Meyers Lake Group
A "Older metamorphic rocks" (Eastern fold belt), petrologically similar rocks, and derived (?) migmatite and augen gneiss.
FOSTER R.
MEYERS L.
FOSTER R.
BRUNNING L.
HICKS IS.
EASTERN FOLD BELT
CHURCHILL
BEST L.
SANDFLY LAKE
WESTERN FOLD BELT
NEEDLE FALLS
WAMNINUTA IS.
DUDDRIDGE L.
55° 30'
106° 15'
55° 30'
105° 45'
SANDFLY LAKE AREA
(EAST HALF)
BLACK BEAR ISLAND LAKE
AREA (WEST HALF)
1 INCH = 4 MILES
2 1 0 2 4 6

Biotite-cordierite-sillimanite-(garnet) and biotite-garnet-(sillimanite) schist, gneiss, and granulite.

The biotitic rocks belonging to unit (5) vary greatly in composition, texture, and general appearance. Typical ("pelitic") rocks are rich in biotite and cordierite and/or garnet (see Plates VI, VII). Five selected thin sections of such rocks contain 1 to 29 per cent quartz, 2 to 33 per cent potassium feldspar, a trace to 52 per cent plagioclase (sodic to intermediate andesine), 12 to 39 per cent biotite, nil to 39 per cent garnet, nil to 24 per cent cordierite and less than 1 to 2 per cent sillimanite. Other minerals which occur in one or more thin sections in trace amounts include apatite, zircon, sphene, graphite, opaque minerals, chlorite (replacing biotite, garnet and cordierite), and sericite (replacing plagioclase and cordierite). Scarce quartzo-feldspathic ("arkosic") varieties also occur. A thin section of a quartzo-feldspathic variety (see Plate VII) contains 48 per cent quartz, 42 per cent potassium feldspar, 7 per cent plagioclase (intermediate or calcic oligoclase), 3 per cent biotite, and traces of each of garnet, sillimanite, apatite, zircon, chlorite, and sericite.

The colour ranges from very pale grey in the quartzo-feldspathic ("arkosic") varieties, to dark brown in the biotite-rich ("pelitic") varieties. The "pelitic" varieties commonly have a distinct reddish cast if the garnet content is high, or a bluish cast with a high content of cordierite. Their texture is generally porphyroblastic. The porphyroblasts may be any of white ovoid to euhedral plagioclase or potassium feldspar, pale-grey-blue to deep-purple ovoid cordierite, or deep-red euhedral to ovoid (Plate VII, 3) or spongy-looking (Plate VII, 2) garnet. These porphyroblasts are usually less than one-half inch in diameter. Garnet is the only porphyroblastic mineral in the quartzo-feldspathic rocks. It is euhedral or ovoid and may have a diameter of as much as 2 inches (50 mm). Locally both the biotite-rich and quartzo-feldspathic varieties are essentially equigranular and fine-or medium-grained. The grain size of most minerals in the equigranular rocks and the matrix of the porphyroblastic rocks varies from about 0.5 to 3.0 mm. Biotite-rich varieties are generally moderately to strongly schistose, whereas quartzo-feldspathic varieties are

weakly foliate or non-foliate (Plate VII; 5, 6). However, some biotitic varieties which contain numerous small, closely spaced garnets, either lack or have very weak foliation (Plate VII, 3). Gneissic interlayering of quartz-feldspar-rich and biotite-rich layers is present locally but is not common.

In thin sections in which biotite shows a strong preferred orientation there is commonly a general slight elongation of quartz, potassium feldspar, plagioclase, and cordierite grains sub-parallel to the biotite. Garnet does not have this elongation. In such thin sections sillimanite occurs in swarms of small acicular needles (Plate VII, 1) which are generally sub-parallel to the biotite. These are especially common in cordierite but also occur in plagioclase and quartz. Some sillimanite grains occur in close association with biotite and appear to replace it (Plate VII, 1). In thin sections in which biotite lacks or has very weak preferred orientation the other minerals also lack preferred orientation.

Plagioclase-scapolite-clinopyroxene rocks

The plagioclase-scapolite-clinopyroxene rocks are medium to coarse-grained, medium green, and glassy in appearance. A thin, brown-weathering crust is present.

The composition of one thin section is estimated to be 40 per cent plagioclase (labradorite), 35 per cent scapolite, 20 per cent clinopyroxene, and 5 per cent actinolite. Minor and accessory minerals include sphene and calcite. The plagioclase is sericitized.

In part (Plate VII, 8) this rock consists of a simple, non-foliate mosaic of clinopyroxene, scapolite, and plagioclase, with interstitial calcite and occasional rounded granules and subhedral crystals of sphene. The actinolite generally occurs rimming and replacing the clinopyroxene but a few separate grains were noted. Within the mosaic, which has a grain size of 3 to 4 mm, poikiloblastic plagioclase (Plate VII, 7) and clinopyroxene grains are irregularly distributed. These grains are as much as 15 mm in apparent diameter and are crowded with inclusions of the other minerals, including each other.

Hornblende-biotite-clinopyroxene gneiss

This rock type is dark greenish grey on both the fresh and weathered surface and is weakly gneissic. The weathered zone may be as much as 6 mm thick. A thin section (614-41-9) contains 10 per cent quartz, 36 per cent slightly sericitized plagioclase (calcic andesine), 10 per cent biotite, 19 per cent hornblende, 24 per cent clinopyroxene, and traces of each of opaque minerals, apatite, zircon, carbonate, and graphite. The rock consists essentially of an inhomogeneous mosaic of quartz, plagioclase, hornblende, and clinopyroxene, with fairly coarse biotite replacing the other mafic minerals. Average grain size is 3 mm.

MAP SUB-UNIT (6a) HYPERSTHENE AMPHIBOLITE

Hypersthene amphibolite occurs as a mappable unit on the west side of the southern end of the narrow part of the Foster River (55°47'07"N, 105°48'33"W). It also forms a small outcrop about 500 feet east of the southeast corner of Falhun Lake in the Eulas Lake Area. It is intruded by the eastern granitic rocks (unit 13, see Plate XVI, 3) but its relationship to the other rock types of the area is not known.

Two thin sections contain respectively 3 and 4 per cent quartz, 23 and 15 per cent plagioclase (calcic andesine), nil and 4 per cent biotite, 61 and 53 per cent hornblende, 10 and 24 per cent hypersthene, 2 and less than 1 per cent apatite. The plagioclase is slightly sericitized and the biotite is slightly chloritized. This rock type is medium to coarse-grained, non-foliate, and equigranular to porphyroblastic. On the fresh surface it is dark greenish grey to dark brownish grey. The weathered surface varies from a dark chocolate brown to almost black. Hornblende and plagioclase are readily recognizable in hand specimen, but the hypersthene is very difficult to distinguish from the hornblende. A specimen (614-89-4) from the Foster River occurrence is essentially equigranular (Plate VIII, 1 to 3) with a grain size of 3 to 4 mm. Much of the hornblende (Plate VIII, 3) and a few grains of hypersthene have weakly to moderately well-developed sieve texture. The minerals form a non-foliate mosaic

with irregular distribution of light and dark minerals. The opaque mineral or minerals occur in cubic (?) grains up to 2 mm in apparent diameter. Hornblende appears to replace hypersthene, locally, but most boundaries between these minerals are sharp. Plagioclase and quartz are generally interstitial to the mafic minerals.

A specimen (614-100-1) from the Falhun Lake occurrence consists of hornblende porphyroblasts 4 to 6 mm in diameter with interstitial quartz, plagioclase, finer grained hornblende, and hypersthene. The hornblende porphyroblasts contain numerous partly replaced remnants of hypersthene and numerous inclusions of quartz and plagioclase. Biotite occurs in flakes replacing hornblende. The rock is non-foliate.

MAP SUB-UNIT (6b) CLINOPYROXENE AMPHIBOLITE

Clinopyroxene amphibolite occurs on a small island in Sandfly Lake (55°41' 24"N, 106°10'24"W). It has not been found elsewhere in the thesis area. It is medium to coarse grained (3 to 6 mm), equigranular, and non-foliate. On the fresh surface it is a glittering, splendent black with green specks. The weathered zone, up to 1/4 inch thick, is a dark chocolate brown. The fresh rock is quite friable due to a ready separation of individual black hornblende and pale-greenish clinopyroxene grains. It is intruded by a grey aplitic stringer up to 5 inches wide which is of uncertain affinities. Its relationships to the other rock types of the area are unknown.

A thin section (624-Y-3) has a mode of 74.4 per cent hornblende, 25.4 per cent clinopyroxene, and 0.2 per cent opaque minerals. The hornblende and clinopyroxene form a simple mosaic (Plate VIII, 4). The opaque minerals are both interstitial to the other minerals and occur as inclusions in them.

Meyers Lake Group

INTRODUCTION

The Meyers Lake Group, a name proposed by the writer, comprises a sequence of quartz-pebble meta-conglomerate, "pure" quartzite, feldspathic quartzite, calcareous quartzite, and biotite-muscovite-quartz schist. The thickness of the group is estimated as being at least some 1,500 to 2,400 feet. The group is exposed for a strike length of at least 30 miles (see Figure 2, following page).

The Meyers Lake Group has been named because it is distinctly different in lithology from any named group in the Precambrian of Saskatchewan and because it is probably separated from the underlying rocks by an unconformity (see Chapter VIII). It is named after Meyers Lake, Eulas Lake Area, where it was first seen and where it is well exposed.

MAP-UNIT (7)

Introduction

Map-unit (7), the basal unit[1] of the Meyers Lake Group, consists predominantly of meta-conglomerate, with minor quartzites and biotite-muscovite-quartz schist. In most places the rock types are interpreted as being interlayered on the basis of alternating outcrops; no contacts were seen. The quartzite and schist apparently form layers in the meta-conglomerate as much as 100 feet in width. At one place (55°38'22"N, 106°03'10"W) an 8-foot wide bed of quartzite was seen with meta-conglomerate in contact above and below it. The quartzite, an actinolitic (calcareous) variety, appeared to be free of pebbles and to be conformable with the meta-conglomerate. Bedding and cross-bedding were seen in an outcrop of quartz-

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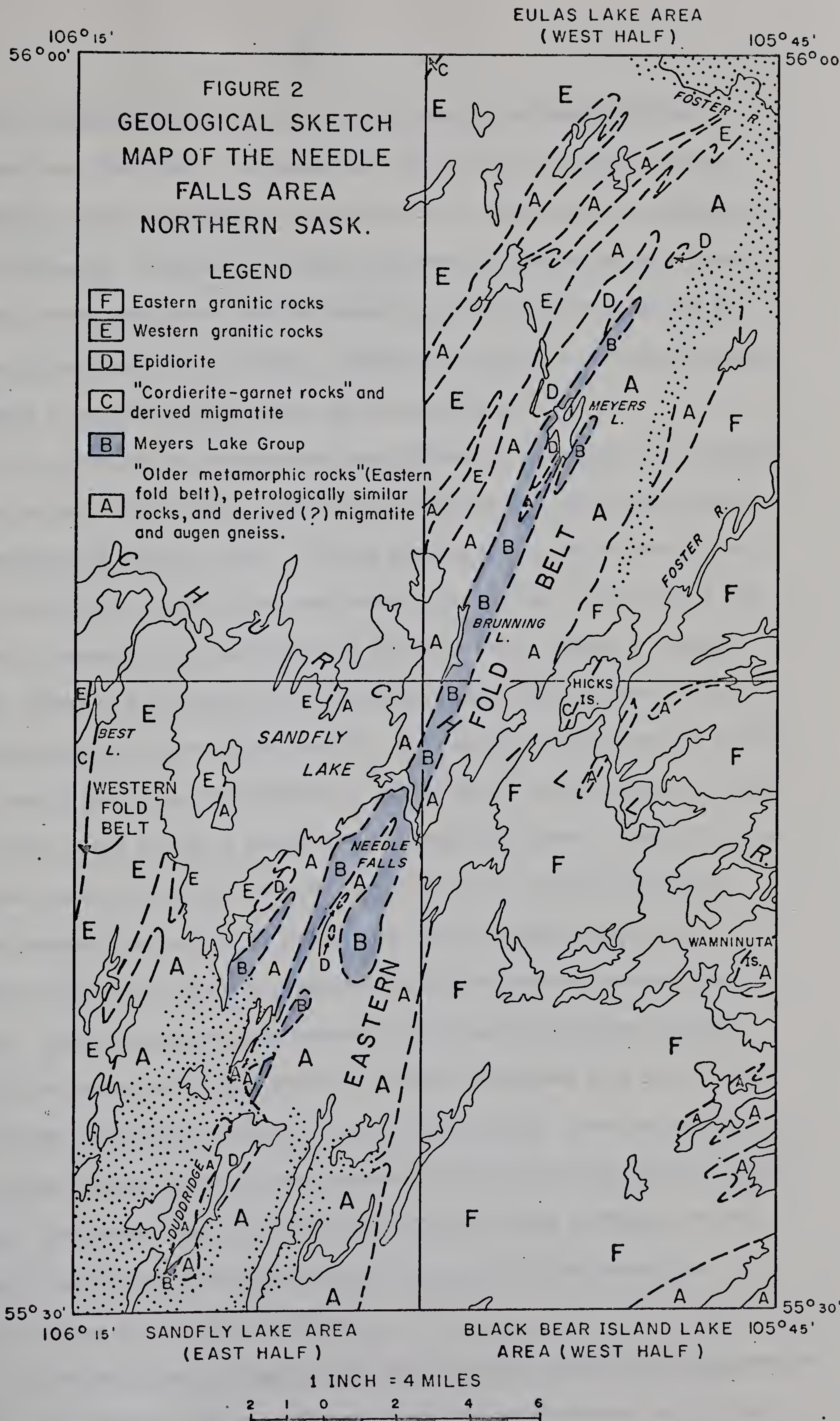
[1] Up to 30 feet of arkosic rocks occur beneath the quartz-pebble meta-conglomerate locally. These rocks may belong to either the Meyers Lake Group or to the "older metamorphic rocks". In view of the uncertainty regarding their stratigraphic position and their lithological resemblance to "meta-arkose" belonging to the "older metamorphic rocks" they have been described with such "meta-arkose".


EULAS LAKE AREA
(WEST HALF)
106° 15'
56° 00'
105° 45'
56° 00'
FIGURE 2
GEOLOGICAL SKETCH
MAP OF THE NEEDLE
FALLS AREA
NORTHERN SASK.
LEGEND
F Eastern granitic rocks
E Western granitic rocks
D Epidiorite
C "Cordierite-garnet rocks" and derived migmatite
B Meyers Lake Group
A "Older metamorphic rocks" (Eastern fold belt), petrologically similar rocks, and derived (?) migmatite and augen gneiss.
FOSTER R.
MEYERS L.
BRUNNING L.
HICKS IS.
FOSTER R.
EASTERN FOLD BELT
CHURCHILL
BEST L.
SANDFLY LAKE
WESTERN FOLD BELT
NEEDLE FALLS
WAMNINUTA IS.
DUDDRIDGE L.
55° 30'
106° 15'
SANDFLY LAKE AREA
(EAST HALF)
BLACK BEAR ISLAND LAKE
AREA (WEST HALF)
105° 45'
55° 30'
1 INCH = 4 MILES
2 1 0 2 4 6

pebble meta-conglomerate on the east side of the south tip of Duddridge Lake, Sandfly Lake Area (East Half). Individual beds are one inch to at least 6 inches thick. Bedding planes are marked by a concentration of mica which has undergone selective weathering. Contacts of the meta-conglomerate with the probably underlying "older metamorphic rocks" and the probably overlying map-units (8) and (9) or with any igneous rocks were not seen. However, at one place the meta-conglomerate appears to be gradational to augen gneiss (see Map-unit 11).

As is shown on the accompanying maps (Figures 16 and 17) unit (7) is persistent along the east limbs of the two major synclines of the area, but seems to occur only sporadically on the west limbs. It is also exposed on the limbs of most of the other synclinal folds. In most of the areas where it is not shown on the maps it may be present, as outcrop is not continuous and the unit is thin. Locally it is almost definitely absent and the lowest unit of the Meyers Lake Group is quartzite (unit 8) or biotite-muscovite-quartz schist (unit 9). For example, on the west limb of the syncline west of Webb Lake at 55°40'09"N, 106°02'06"W, biotite-muscovite-quartz schist outcrops within 20 feet of knobby biotite-plagioclase gneiss. The latter is not of mappable width and has been included in map-unit (11). Both the schist and gneiss are probably less resistant to erosion than the meta-conglomerate and it is exceedingly unlikely that there is un-exposed meta-conglomerate between these rock types. About one-quarter mile southeast of this point on the same fold limb quartzite is in contact with augen gneiss. The latter is believed to be derived from the hornblende-biotite rocks which form most of map-unit (2). Here the contact is parallel to the foliation and no primary sedimentary features were observed in either rock type. The greatest apparent thickness of unit (7) is about 1,300 feet, on the west limb of the syncline immediately west of Webb Lake, but in general the apparent thickness is about 100 to 400 feet.

Of the rock types forming unit (7), only the quartz-pebble meta-conglomerate will be described below. The quartzites and biotite-muscovite-quartz schist do not

appear to differ from the similar rocks described as parts of map-units (8) and (9) respectively.

Quartz-pebble meta-conglomerate

Two types of quartz-pebble meta-conglomerate occur in unit (7). The most common is characterized by a muscovitic and feldspathic matrix and the presence of porphyroblasts and/or pebbles of pink feldspar. The second type has a grey, biotitic matrix and lacks pink feldspar.

The muscovitic and biotitic types areunusually well exposed respectively on the west side of Orr Lake (55°49'53"N, 105°54'05"W, see Plate IX, 1) and at the south end of Duddridge Lake (55°30'53"N, 106°10'37"W). The two types have not been seen in contact, although noted in the same outcrop (at 55°41'23"N, 106°01'28"W), so their relationship is uncertain. Both types contain numerous elongated, glassy, grey to white, ellipsoidal quartz pebbles (Plate IX, 1,3) which in almost all outcrops have a ratio of longest axis to shortest axis which varies from about 10 : 1 to 2 : 1. The longest axis is usually 1/2 inch to 2 inches, but may be as much as 8 inches. In one outcrop of muscovitic conglomerate on the north side of the easternmost bay of Meyers Lake the pebbles have been stretched into sheets of quartz up to 5 feet long, generally 1/4 inch or less thick, and of unknown depth (greater than 2 feet). The weathered surface of the matrix of the muscovitic type is pink to grey and that of the biotitic type is grey. The former type shows local iron staining due to disseminated magnetite and ilmenite.

Sixteen thin sections of both types of quartz-pebble meta-conglomerate have been studied in an attempt to determine the origin of the quartz pebbles, and whether the feldspathic grains in the muscovitic type are pebbles or porphyroblasts. The quartz pebbles show weak to strong undulatory extinction. In most specimens they have been separated by deformation into domains of different average extinction position that have strongly to moderately sutured mutual boundaries (Plate VIII,

5, 6, 7). The boundaries of the pebbles themselves vary from smooth and distinct, in thin sections of less deformed rocks, to highly granulated and irregular in some stretched meta-conglomerates. A fine dust of opaque minerals and numerous small bubbles with random orientation are present in all quartz pebbles. A few muscovite flakes were noted in many pebbles in the muscovitic conglomerate and a few biotite flakes in pebbles in the biotitic meta-conglomerate. Minute grains of apatite and zircon were distinguished in some pebbles. The absence of large grains of other minerals stable under weathering conditions in the quartz pebbles, and the random orientation of the fine dust present, suggest that these pebbles are not aggregates of small grains and are probably derived from vein or pegmatitic quartz or chert rather than from sandstone or quartzite.

In the muscovitic types of meta-conglomerate most large grains of feldspar are seen in thin sections to be porphyroblasts of microcline with slightly ragged embayed margins and a sieve texture. As they lack granulation, or at most show slight marginal granulation, they were probably introduced after most of the deformation of the meta-conglomerate. In a few thin sections of highly stretched and granulated meta-conglomerate the microcline consists of an aggregate of slightly granulated grains that may represent an original pebble of feldspar. It is more likely that these aggregates, too, consist of introduced feldspar, and that the rock has undergone more prolonged or intensive deformation.

The matrix of the muscovitic meta-conglomerate consists mainly of quartz, potassium feldspar, plagioclase, muscovite, and opaque minerals. Biotite or chlorite are commonly present but not abundant. Zircon is present in almost every thin section, sphene in over half, apatite in a few, and a single grain of tourmaline was noted in one section. Quartz, muscovite, biotite, chlorite, microcline, and plagioclase form a granulated mosaic in most thin sections. Interstitial microcline is always present and in some sections replaces plagioclase. The grain size of the major minerals of the matrix varies from 0.3 to 1.5 mm. There is generally a

sub-parallel alignment of muscovite, biotite, and chlorite. The opaque minerals in part are parallel to the micas and in part cut across them.

The matrix of the biotitic meta-conglomerate consists of a simple mosaic of quartz and biotite with minor accessory zircon, sphene, apatite, and opaque minerals. A few grains of garnet, with very embayed margins, containing a few inclusions of quartz and biotite, also occur.

MAP-UNIT (8)

Introduction

Map-unit (8), the largest unit of the Meyers Lake Group, consists predominantly of quartzite, feldspathic quartzite, and calcareous quartzite, with lesser amounts of biotite-muscovite-quartz schist and very minor meta-conglomerate. The quartzites and schist are interlayered (see Plate X, 1, 3; Plate XXII, 3; Plate XXIII, 1-3) and are undoubtedly part of a conformable sedimentary sequence. Individual layers range from less than a tenth of an inch to several feet in thickness. Only five occurrences of meta-conglomerate were noted within map-unit (8). All five occur as thin, unmappable layers within the quartzite. The rocks forming this unit were not observed in contact with older or younger metamorphic rocks. The only intrusive rock noted in contact with them is a thin, cross-cutting pegmatite stringer (Plate X, 2).

The biotite-muscovite-quartz schist does not appear to differ from that described as part of map-unit (9) and will not be described here. Four of the five outcrops of meta-conglomerate are of the same types as the meta-conglomerate forming most of map-unit (7) and will not be further described. The fifth outcrop (55°38'12"N, 106°02'37"W) consists of quartz pebbles in a matrix of calcareous (actinolitic) quartzite (Plate IX, 2). The pebbles are essentially similar to those in the biotitic variety of meta-conglomerate which forms part of map-unit (7) and the matrix is very similar to the calcareous variety of quartzite which will be described in the following paragraphs.

Quartzite, feldspathic quartzite, and calcareous quartzite

The quartzites belonging to map-unit (8) are estimated to consist of at least 65 per cent "pure" quartzites and not more than 20 per cent feldspathic quartzites and 15 per cent calcareous quartzites. The calcareous quartzite and the most common variety of feldspathic quartzite (grey feldspathic quartzite) occur throughout the map-unit interlayered with the "pure" quartzites. Individual layers (Plate X, 1) vary from about 0.1 to 3 inches in thickness and are in some cases separated by thin micaceous films. These layers are believed to represent bedding, as similar layering in one outcrop is definitely an example of cross-bedding (Plate X, 2). Interlayered grey feldspathic quartzite and "pure" quartzite are well exposed on the shore of Meyers Lake at 55°50'53"N, 105° 54'58"W. Type locations for interlayered calcareous and "pure" quartzites are those shown in Plate X.

Two uncommon varieties of feldspathic quartzite occur. One of these is confined to the syncline immediately east of the most southern bay of Sandfly Lake. A shoreline outcrop occurs at 55°37'20"N, 106°07'10"W. This variety is characterized by the presence of flecks of pink potassium feldspar scattered through the predominant glassy grey quartz. The other variety (pink arkosic quartzite) always occurs in layers less than 5 feet thick and seems to be confined to the lowermost 300 feet of the quartzite. An example may be seen at 55°38'50"N, 106°03'05"W.

The "pure" quartzites are pale grey to white on both the fresh and weathered surface, glassy in appearance, and massive. Individual grains can rarely be distinguished. Two thin sections each contain 91 per cent quartz and contain respectively 3 and 8 per cent potassium feldspar, 2 per cent and nil plagioclase (sodic andesine) and 3 per cent and 1 per cent muscovite. Both contain traces of each of biotite, apatite, zircon, tourmaline, and opaque minerals and one contains a trace of chlorite replacing the biotite. Quartz and feldspar form a sutured mosaic (Plate XI, 1, 2). The micas are in part interstitial to the quartz and feldspar but generally cut across and through them. The accessory minerals are interstitial to quartz grains.

The grey feldspathic quartzite is pale grey and similar in appearance to the "pure" quartzite. It may be distinguished in the field from the "pure" quartzite by its more ready weathering and chalky-white weathered surface. Two thin sections contain respectively 74 and 75 per cent quartz, 20 and 16 per cent potassium feldspar, and 6 and 8 per cent muscovite. Both contain traces of each of plagioclase, apatite, sphene, zircon, and opaque minerals. One contains traces of biotite and tourmaline. The grey feldspathic quartzite is similar in texture to the "pure" quartzite.

The feldspathic quartzite characterized by the presence of pink feldspar flecks is similar in composition and texture to the grey feldspathic quartzite.

The arkosic quartzite is pink on both the fresh and weathered surface. It is commonly massive and fine-grained. Two thin sections contain respectively 66 and 44 per cent quartz, 25 and 13 per cent potassium feldspar, and 8 and 43 per cent muscovite. Both contain traces of plagioclase, apatite, sphene, and opaque minerals. One contains a trace of zircon and the other contains 1 per cent tourmaline. The texture of the arkosic quartzite is similar to that of the "pure" quartzite.

Calcareous quartzite is in part a uniform, fine-grained rock which is pale green in colour and in part a grey or pale green rock containing medium green, acicular actinolite needles up to one inch (25 mm) long. These needles may be evenly disseminated or occur as sub-parallel or radiating aggregates. Generally the weathered surface is nearly indistinguishable from the fresh surface but some highly calcareous varieties weather to a chocolate-brown colour to a depth of as much as 6 mm. Three thin sections of calcareous quartzite contain 64 to 76 per cent quartz, 9 to 14 per cent potassium feldspar, nil to 4 per cent plagioclase (sodic to intermediate andesine), 11 to 16 per cent actinolite, nil to 6 per cent epidote, and nil to 2 per cent carbonate. Other minerals which occur in trace amounts in one or more thin sections include muscovite, biotite, chlorite, clinopyroxene, apatite, sphene, zircon, tourmaline, and opaque minerals. The quartz and potassium feldspar form a sutured mosaic. The other minerals are for the most part

interstitial to quartz grains or ovoid areas of quartz which were probably originally detrital grains (Plate XI, 4). Some actinolite and clinopyroxene grains have grown into the quartz and potassium feldspar and the actinolite occurs in one section as remarkable elongate porphyroblasts with a pronounced sieve texture (Plate XI, 7).

MAP-UNIT (9)

Map-unit (9) consists predominantly of biotite-muscovite-quartz schist and gneiss, with minor interlayered quartzite. This unit is best considered as a pelite-rich facies of the quartzite-rich sequence which is mapped as unit (8). The rocks mapped as unit (9) occur throughout unit (8) from near its base to near the top of the exposed section. The biotite-muscovite-quartz schist has not been observed in contact with any rock type other than the quartzite.

The relationships of the schist and gneiss to the quartzite have been discussed previously and the quartzites have been described (see map-unit (8)). These will not be considered further. The schist and gneiss are described in the following section.

Biotite-muscovite-quartz schist and gneiss

The biotite-muscovite-quartz schist and gneiss is a highly schistose, silvery-grey to dark-brown rock. A gneissosity is generally present due to mica-rich and quartz-rich layers. Crenulations are fairly common. The grain size may be fairly coarse, and mica flakes as much as 1 cm in diameter can be detached from the rock, but fine-grained varieties occur. The weathered surface is light grey or dull grey or various rusty-red shades. Good exposures may be seen at 55°49'45"N, 105°55'47"W (see Plate X, 3) and 55°46'50"N, 105°57'40"W.

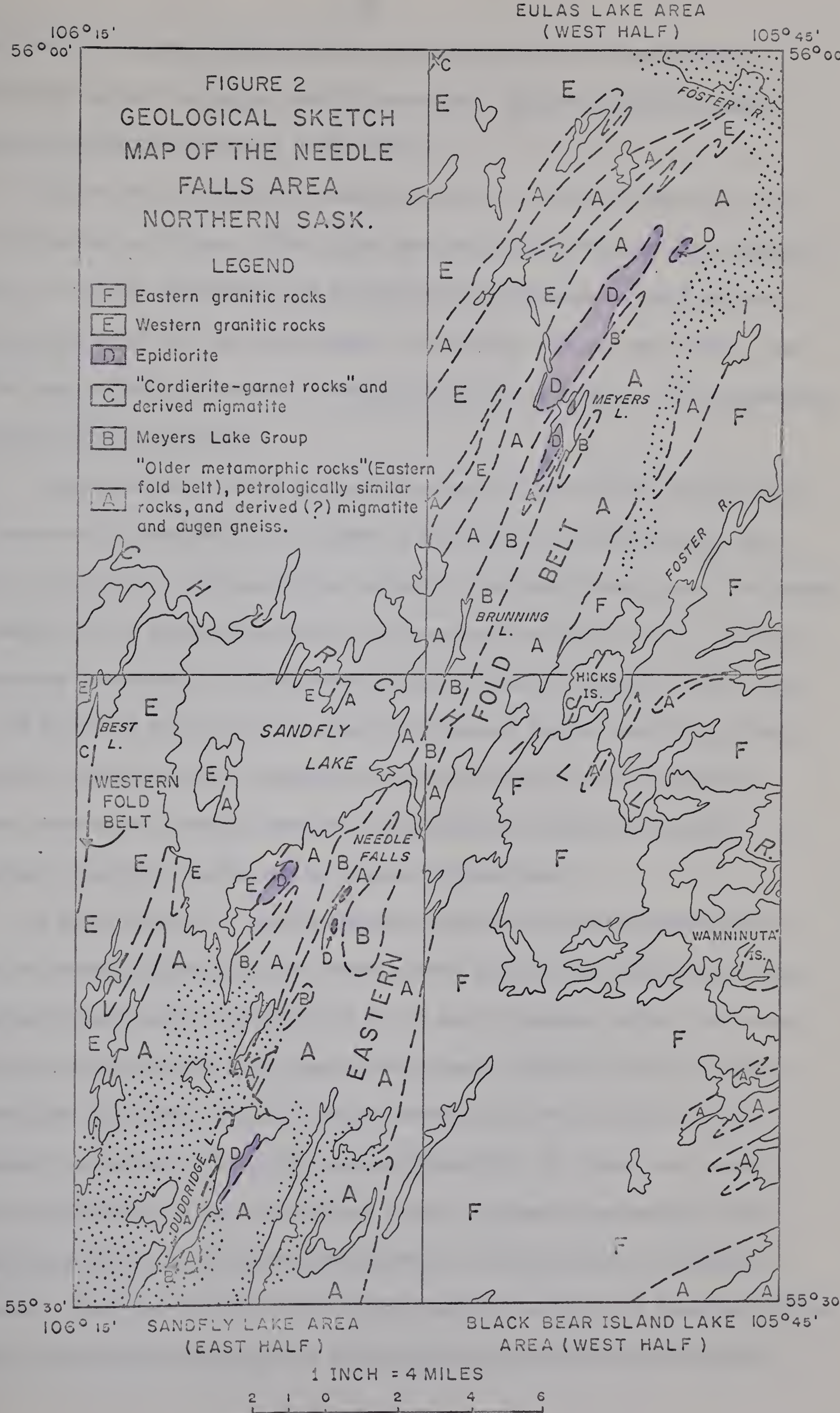
Representative thin sections contain 12 to 42 per cent quartz, nil to 2 per cent potassium feldspar, nil to 28 per cent plagioclase (sodic to intermediate andesine), 17 to 58 per cent muscovite, 5 to 38 per cent biotite, and nil to 18 per cent andalusite. Minerals forming trace amounts of one or more thin sections include apatite, zircon, sphene, tourmaline, opaque minerals, graphite, and sillimanite (accompanying andalusite only).

In thin section a strong sub-parallel alignment of interleaved biotite and muscovite flakes (Plate XII) is seen. Quartz and feldspar occur as individual interstitial grains and as mosaics of slightly to strongly elongate grains. Andalusite occurs in porphyroblasts elongated parallel to foliation. It contains many inclusions of quartz, biotite, and opaque minerals, (Plate XII, 5, 6) and rare inclusions of other minerals. Locally andalusite cuts across and replaces biotite (Plate XII, 7) but elsewhere in the same thin section it is probably replaced by biotite (Plate XII, 4). Some andalusite grains are curved around the axes of crenulations elsewhere outlined by mica, indicating either that the andalusite has been deformed or that it has developed from the mica after folding (Plate XII, 6, 8). Another grain has a quartz-rich zone on one side of it which could be a pressure shadow effect and appears to have been rotated (Plate XII, 4, 5). This grain also appears to have biotite deflected around it. Sillimanite occurs as little wispy fibrolite aggregates (Plate XII, 5) and rare coarser grains replacing both biotite and andalusite.

Metamorphosed Intrusive Rocks

MAP-UNIT (10) EPIDIORITE

Epidiorite forms several plutons in the eastern fold belt (see Figure 2, following page). The largest body, west and north of Meyers Lake, Eulas Lake Area, is about 6 miles long and about one-half to three-quarters of a mile wide. Inclusions of similar rocks are fairly common within the migmatite and augen gneiss in the western half of the eastern fold belt. Epidiorite dykes and sills were noted within the hornblende-biotite rocks (map-unit 2) and inclusions of the hornblende-biotite rocks occur in epidiorite (Plate XIII, 1). One small outcrop of epidiorite occurs within a synclinal trough of quartzite (map-unit 8) about half way between the synclinal axis and the contact between quartzite and quartz-pebble meta-conglomerate (map-unit 7). The contact between the epidiorite and the quartzite is


EULAS LAKE AREA
(WEST HALF)
106° 15'
56° 00'
105° 45'
56° 00'
FIGURE 2
GEOLOGICAL SKETCH
MAP OF THE NEEDLE
FALLS AREA
NORTHERN SASK.
LEGEND
F Eastern granitic rocks
E Western granitic rocks
D Epidiorite
C "Cordierite-garnet rocks" and derived migmatite
B Meyers Lake Group
A "Older metamorphic rocks" (Eastern fold belt), petrologically similar rocks, and derived (?) migmatite and augen gneiss.
FOSTER R.
MEYERS L.
BRUNNING L.
HICKS IS.
BEST L.
SANDFLY
LAKE
WESTERN
FOLD
BELT
NEEDLE
FALLS
EASTERN FOLD BELT
CHURCHILL
DUDDRIDGE L.
WAMNINUTA IS.
55° 30'
106° 15'
55° 30'
105° 45'
SANDFLY LAKE AREA
(EAST HALF)
BLACK BEAR ISLAND LAKE
AREA (WEST HALF)
1 INCH = 4 MILES
2 1 0 2 4 6

not exposed but it seems probable that the epidiorite reached this position by intrusion and hence it is younger than the quartzite. The best readily accessible exposures of epidiorite are shown in Plate XIII.

Thin sections of epidiorite contain less than 1 to 2 per cent quartz, nil to 4 per cent potassium feldspar, 48 to 75 per cent plagioclase (intermediate andesine), less than 1 to 18 per cent biotite, 13 to 41 per cent hornblende, nil to 2 per cent opaque minerals, nil to 1 per cent epidote, less than one to 1 per cent sphene, and less than one to 3 per cent apatite. Allanite occurs in two sections. The plagioclase is generally slightly sericitized.

Megascopically much of the epidiorite appears to be a fresh, unmetamorphosed igneous rock (Plate XIII, 2). It seems to be medium to coarse-grained, equigranular, and massive, and to consist of euhedral to subhedral stubby green hornblende and subhedral white plagioclase grains, each ranging from 3 mm to 8 mm in diameter. In places the hornblende is accompanied by coarse flakes of secondary biotite, and within 10 to 20 feet of the contacts of the two plutons at Meyers Lake the epidiorite is altered to a biotite schist. On most outcrops the weathered surface resembles the fresh surface, but shoreline outcrops, just above water level, show coarse pitting due to selective weathering and erosion of hornblende.

In thin section, it is obvious that the epidiorite has been metamorphosed. The large "stubby hornblende grains" noted in hand specimen are seen actually to be aggregates of small grains, generally 0.2 to 1.0 mm in diameter, which, with associated biotite and sphene, seem to preserve the general outline of original pyroxene or hornblende (Plate XIV, 1 to 7). Coarser hornblende grains, as much as 2.0 mm in diameter, are present in some thin sections (Plate XIV, 5). These have ragged outlines and many have a pronounced sieve texture, suggesting metamorphic origin. In most thin sections some large plagioclase grains, as much as 8 mm in diameter, are present. They have complex twinning and locally show bent twin lamellae and are fractured. They probably represent the original plagioclase of this rock (Plate XIV,

1, 2, 5, 6, 8). These grains are altered in part to a mosaic of small (generally 0.2 to 0.3 mm), probably metamorphic plagioclase grains (Plate XIV, 3, 4). Locally there is a weak alignment of secondary biotite flakes and aggregates as much as 3 mm in length.

Metasomatized and Migmatitic Rocks

INTRODUCTION

The group comprises all rocks which show evidence in the field of having undergone metasomatism and also all rocks in whose formation mobilization and/or intrusion of granitic material has played a role. Such rocks, although abundant in the thesis area, are most difficult to delineate because of their nature. All contacts shown are arbitrary. To a large degree the precise classification of these rocks in a given outcrop or area is a matter of personal opinion and, particularly in the case of the migmatitic rocks, will vary according to the scale of mapping.

ANTHOPHYLLITE-CORDIERITE-BIOTITE GNEISS

This rock type occurs within the body of map sub-unit (3a) which extends north-northeast for about 7 miles from the Churchill River between Sandfly Lake and Kinosaskaw Lake. The anthophyllite-cordierite-biotite gneiss is well foliated and dark brownish to bluish grey. It contains ovoid, pale-bluish cordierite and white plagioclase porphyroblasts, both of which are up to 10 mm in maximum diameter and elongate parallel to the foliation; and euhedral to subhedral, elongate, dark-straw-brown anthophyllite porphyroblasts up to 12 mm long that are disposed in random orientations in and across the foliation planes.

A typical thin section (614-39-6) consists of 30 per cent quartz, 12 per cent plagioclase (intermediate oligoclase), 15 per cent biotite, 7 per cent chlorite, 22 per cent cordierite, and 14 per cent anthophyllite. Less than one per cent of each of zircon, apatite, and opaque minerals are present. Alteration products

include chlorite, sericite, a pale-yellow-brown isotropic substance, and a yellow birefringent substance.

In thin section the porphyroblasts (Plate XV, 1-3) are seen to occur in a matrix (Plate XV, 1, 2) whose average grain size is about 0.5 to 2.0 mm. The matrix consists of a mosaic of quartz, plagioclase, and biotite with smooth mutual boundaries. The biotite flakes show a sub-parallel alignment. The matrix contains biotite-rich and biotite-poor layers.

The cordierite porphyroblasts contain a few inclusions of biotite, quartz, plagioclase, and the accessory minerals. In general, they have slightly ragged, embayed margins. Alteration of cordierite to pale-green chlorite or a pale-yellow-brown isotropic mineral is common and most grains are slightly cloudy. Most of the alteration occurs in fractures perpendicular to the margins of the grains, but some grains have been partly converted to felty aggregates of chlorite flakes (Plate XV, 2). The plagioclase porphyroblasts are slightly sericitized. They contain numerous inclusions of quartz and biotite (Plate XV, 2) and rare inclusions of accessory minerals. The anthophyllite porphyroblasts contain inclusions of all of the other minerals. Most grains show alteration to a yellowish birefringent substance along cleavage cracks.

MAP-UNIT (11)

Introduction

The rocks comprising this unit are of widespread occurrence in the thesis area. They are common in the granitic rocks (map-units 12 and 13) east and west of the eastern fold belt, and form a substantial part of this fold belt itself. They have been grouped together in one unit because: (1) there is some gradation from one type to another; (2) there are large areas where different types are intimately associated and cannot be mapped separately; and (3) for the most part they probably have a similar origin, in that potassium metasomatism and mobilization and/or intrusion of granitic material has had some part in their formation.

Porphyroblastic potassium feldspar gneiss and augen gneiss

The porphyroblastic gneiss (Plate XVI, 1) consists of euhedral to subhedral, pink potassium feldspar crystals, with either no alignment and elongation or weak alignment and elongation, in various matrices. It is gradational to a type of augen gneiss, which consists of aligned, elongate, ovoid pink potassium feldspar porphyroblasts (augen) in similar matrices (Plate XV, 5). This type of augen gneiss is gradational to two other varieties. In one of these the augen are ovoid quartzo-feldspathic aggregates and in the other they are elongated into streaky feldspathic veins and lenses. As the quartzo-feldspathic aggregates and feldspathic veins become more extensive the rock grades into a type of migmatite.

The differing matrices correspond to several of the metamorphic rock types of the area. Matrices rich in biotite, with or without subordinate hornblende, are by far the most common and probably indicate derivation from the hornblende-biotite (map-unit 2) and biotite (map-unit 3) rocks of the thesis area. Augen or porphyroblastic gneisses grading into and derived from quartz-pebble meta-conglomerate (map-unit 7), acidic meta-volcanic (?) rocks (map-unit 4), and epidiorite (map-unit 10) also occur.

The porphyroblasts and augen, except for the augen that are quartzo-feldspathic aggregates or are greatly elongated, are generally one inch (2.5 cm) or less in maximum diameter but may be as much as 3 inches (7.6 cm). Most of the other major minerals present range from about 0.5 mm to 3 mm, but plagioclase occurs in porphyroblastic grains as much as about 10 mm in diameter.

Examination of thin sections of augen and porphyroblastic gneiss shows that there is considerable variation in texture and in the amounts of various minerals present. Quartz, potassium feldspar and sericitized plagioclase (sodic oligoclase to sodic andesine) are found in every thin section, and biotite, usually with minor chlorite, in all except the augen gneiss derived from meta-conglomerate (unit 7). There is commonly minor myrmekite fringing potassium feldspar. Hornblende and

muscovite each occur in a few thin sections. Apatite, zircon, sphene, and opaque minerals are present in almost every thin section. Epidote, with minor associated allanite, was noted in two thin sections.

Texturally, there is a continuous variation from an almost non-foliate, weakly granulated rock to a strongly foliate, highly granulated gneiss. In the former the potassium feldspar porphyroblasts consist of slightly poikiloblastic, rectangular grains with weakly granulated and embayed margins (Plate XV, 4). The less common and smaller plagioclase porphyroblasts are similar. With increasing granulation the porphyroblasts become ovoid grains, typical augen, surrounded by a fine-grained aggregate. In the most highly deformed rocks the entire porphyroblast is altered to an aggregate of fine grains of potassium feldspar with scarce grains of other minerals. In the weakly granulated rocks the matrix consists of an essentially equigranular mosaic in which there is a marked concentration of the mafic minerals and accessory minerals. As the degree of granulation increases the concentration of mafic minerals and accessory minerals in the matrix is not nearly as obvious, as they are drawn out into elongate streaks amid fine granular feldspars derived from the porphyroblasts. Because of local variations in degree of granulation, the texture becomes seriate. Biotite is recrystallized and cuts through grains of other minerals, including some large potassium feldspar porphyroblasts which otherwise appear to be little affected by the granulation. Curved twin lamellae in plagioclase were noted in several thin sections.

<u>Migmatite</u>

Migmatite, in the thesis area, shows much variation in form and composition, although one type is by far the most common. This is characterized by contorted folding (Plate XVIII, 2, 3). This type of migmatite has both sharply defined and gradational contacts between the quartzo-feldspathic component and the mafic component in any given outcrop. The quartzo-feldspathic material may occur as dykes, sills, or discontinuous streaks. This migmatite is gradational to augen gneiss,

but transitions (Plate XVII, 1, 2) also occur between it and much less distorted "lit-par-lit" gneisses (Plate XVII, 3), in which the quartzo-feldspathic material is in the form of parallel "sills" of granitic- and aplitic-appearing material up to a foot wide and traceable for hundreds of feet. Another type of migmatite, using the term in a broad sense, is developed only in fairly massive, competent rocks such as amphibolite, epidiorite, and hypersthene amphibolite. This consists of blocks of the country rock separated by a stockwork of granitic or aplitic dykes which seem to follow joint directions (Plate XVI, 3). This type of migmatite (agmatite) occurs in close spatial association with ptygmatically-folded migmatite developed in foliated rocks, suggesting that the difference in form of the migmatite is due to the different physical properties of the host rock. Migmatites are developed from all of the metamorphic rocks of the thesis area except those belonging to the Meyers Lake Group.

Granitic gneiss

The term "granitic gneiss" has been used, in this thesis, for migmatitic rocks in which the quartzo-feldspathic layers are sub-parallel, form more than 50 per cent of the rock, and commonly have gradational contacts with the more mafic layers. Locally these rocks are transitional to gneissic granitic rocks, included in unit (12), an arbitrary separation being made where mafic-rich streaks in the rocks are continuous over not more than a few feet. Hence the granitic gneiss, as shown on the maps, probably includes some gneissic intrusive rocks.

Chapter III

GENERAL DESCRIPTION OF THE INTRUSIVE ROCKS

INTRODUCTION

The western granitic rocks are probably the oldest of the units grouped under this heading (see Chapter VI). The relationships of the other units are uncertain. Some of the pegmatites west of the eastern fold belt may be older than the eastern granitic rocks. However, the absence of cataclastic textures and the occurrence of chilled margins suggests that most if not all formed late in the history of the area.

MAP UNIT (12) WESTERN GRANITIC ROCKS

The western granitic rocks include all the granitic rocks west of the eastern fold belt and probably the small granitic bodies within the eastern fold belt near Meyers Lake, Eulas Lake Area.

The composition of thin sections of typical rocks range from 29 to 43 per cent quartz, 29 to 41 per cent potassium feldspar, 20 to 35 per cent plagioclase (sodic to intermediate oligoclase), a trace to 3 per cent biotite, and nil to 4 per cent hornblende. Minerals occurring in trace amounts in one or more thin sections include apatite, sphene, zircon, opaque minerals, allanite, epidote, sericite, and chlorite. These thin sections all have the composition of quartz monzonite in William's classification (Williams, Turner, and Gilbert, 1955). This classification is used for intrusive rocks throughout this thesis. A thin section (614-28-8) from the fringe of a migmatite zone is also quartz monzonite but is much higher in plagioclase and lower in quartz. It contains 11 per cent quartz, 29 per cent potassium feldspar, 52 per cent plagiocalse (intermediate oligoclase), 2 per cent biotite, 5 per cent hornblende, 3 per cent epidote and opaque minerals, and traces of apatite, sphene, zircon and sericite. A small but mappable area of monzonite (sub-unit 12a) occurs on the north shore of Sandfly Lake. This appears to be the rock type

referred to by Frarey (1950, p. 6) as "hornblende granite". Two thin sections (624-97-3a; 624-97-3b) contain respectively 1 and 7 per cent quartz, 54 and 48 per cent potassium feldspar, 37 and 40 per cent plagioclase (sodic oligoclase), 2 and 3 per cent biotite, and 6 and 1 per cent hornblende. Minerals occurring in trace amounts include apatite, sphene, zircon, opaque minerals, epidote, and sericite.

The western granitic rocks are commonly pink, although grey varieties are locally abundant. Contacts between colour varieties are gradational. The weathered surface is either rusty brown due to iron staining or more commonly pink. The western granitic rocks generally have a weak, very irregular, swirling foliation or lack foliation. In hand specimen they appear to be fine to medium-grained and equigranular. In thin section, they are seen to consist of an angular mosaic of grains with irregular margins whose average size ranges from 0.5 mm to 2 mm. (Plate XIX, 1, 2). The mosaic is non-foliate or weakly foliate due to a sub-parallel alignment of elongate grains of quartz, feldspar, biotite, and hornblende. Granulation is common in every thin section and some intricately sutured quartz boundaries were noted. Bent plagioclase twin lamellae are present in most thin sections. In several thin sections grains or aggregates of quartz (Plate XIX, 4) and aggregates of grains of potassium feldspar (Plate XIX, 3) and plagioclase 3 mm to 7 mm in diameter occur. These appear to have been original grains and to indicate the original grain size.

HORNBLENDE QUARTZ DIORITE

Hornblende quartz diorite occurs as a number of small inclusions, with both sharp and gradational boundaries, in the eastern granitic rocks (map-unit 13). It is particularly noticeable in cliff faces on the west side of the northernmost bay of Kinosaskaw Lake, Eulas Lake Area (West Half), but such inclusions have been noted in outcrops along the west bank of the Foster River, just above its junction with the Churchill River, and probably occur elsewhere.

The quartz diorite is grey, medium to coarse-grained, non-foliated and

equigranular. In the only thin section studied, from sample 614-44-10, the average grain size is 3 to 4 mm and the texture is granitic. The constituent minerals are fresh and show no evidence of granulation. A point count indicates a mode of 11 per cent quartz, 62 per cent plagioclase (An_{33}), 5 per cent biotite, and 22 per cent hornblende. Accessory minerals include apatite, sphene, opaque minerals and epidote. The plagioclase is slightly sericitized.

This appears to be a fresh plutonic rock. Its mineralogical composition is unlike any of the mappable bodies of plutonic rocks in the thesis area.

UNIT (13) EASTERN GRANITIC ROCKS

The eastern granitic rocks vary in composition from quartz monzonite to biotite quartz diorite (trondhjemite). Representative thin sections of equigranular rocks contain 11 to 42 per cent quartz, a trace to 31 per cent potassium feldspar, 34 to 65 per cent plagioclase (calcic oligoclase to sodic andesine), 2 to 20 per cent biotite, and nil to 3 per cent hornblende. Minerals present in trace amounts in one or more thin sections include apatite, sphene, zircon, garnet, opaque minerals, epidote, chlorite, sericite, and carbonate. In one section there is 2 per cent sericite. A porphyritic or porphyroblastic variety is too coarse grained for modal analysis but its overall bulk composition is probably granodioritic.

The eastern granitic rocks are in general medium- to coarse-grained, equigranular, and lack foliation or have a weak foliation. A grey porphyritic or porphyroblastic variety (13a), apparently gradational into the normal type, forms most of Hadley Island in the Black Bear Island Lake Area (West Half) and extends east into the Black Bear Island Lake Area (East Half), mapped by Morris (1965), and west along the south shore of Hadley Bay. The megacrysts generally are 1 inch to 2 inches in diameter. Porphyritic or porphyroblastic rocks also occur along the western margin of the eastern granitic ~~rocks~~, in a zone which is gradational into the porphyroblastic potassium feldspar gneiss-augen gneiss-migmatite complex

(sub-unit 11a), which forms part of the eastern fold belt. The eastern granitic rocks are predominantly grey, but pink varieties are common. Contacts between colour varieties are gradational. The weathered surface is generally the same colour as the fresh surface, although red-brown to dark-brown colours occur locally due to iron staining. Grain size of the equigranular rocks and the matrix of the porphyritic or porphyroblastic types ranges from 2 mm to 8 mm in different thin sections. The texture is essentially granitic (Plate XIX, 5). The mafic minerals tend to occur in interstitial clumps that have a concentration of accessory minerals associated with them. The potassium feldspar megacrysts in sub-unit (13a) have quite irregular margins (Plate XIX, 6) and contain inclusions of all the other minerals present. A few bent plagioclase twin lamellae were noted in most thin sections and there is local granulation (not obviously related to any known faults) but not the widespread granulation noted in the western granitic rocks. Sutured quartz grains occur.

UNIT (14) PEGMATITE

Pegmatite is of widespread occurrence throughout the thesis area, but is only locally abundant. Most pegmatite bodies are small sills and lenses, generally no more than ten feet wide and a few hundred feet long. A few are definitely cross-cutting and dyke-like. Much larger pegmatite bodies also occur, such as the one on the north shore of MacDougall Bay, Besnard Lake, in the southeast corner of the Black Bear Island Lake Area (West Half), and the numerous bodies in and near Sandfly Lake.

The most common type of pegmatite consists of coarse white or pink potassium feldspar and white plagioclase with subordinate glassy quartz and biotite. Graphic intergrowths of quartz and potassium feldspar are common. The potassium feldspar and plagioclase are essentially equigranular in most pegmatite bodies. "Porphyritic" varieties with phenocrysts of potassium feldspar up to ten inches in diameter occur near Sandfly Lake. Muscovite occurs in the "porphyritic"

pegmatites and in small lens-like pegmatitic bodies within the meta-arkose (unit 1). Cordierite, garnet, and sillimanite are found in pegmatitic lenses within the biotite-cordierite-sillimanite-garnet rocks (unit 5). Magnetite is of widespread but minor occurrence in pegmatites within mafic rocks. It is concentrated near the margins of these pegmatites. As much as 50 per cent of coarse magnetite is present locally, but the magnetite pegmatites probably average less than one percent magnetite. Black tourmaline was noted in three unusual pegmatites (Plate XX, 2) near Sandfly Lake, as shown on the accompanying map of this area.

The tourmaline-bearing pegmatites (Plate XX, 2) and the "porphyritic" pegmatites (Plate XX, 3) of Sandfly Lake and vicinity may be related as one of the "porphyritic" pegmatites contains tourmaline. The "porphyritic" pegmatites consist of crystals of pink potassium feldspar, generally 6 to 10 inches in diameter, in a paler pink to pale-greyish pegmatitic matrix of potassium feldspar, plagioclase, quartz, and biotite, with minor local muscovite and tourmaline. The large potassium feldspar crystals contain a graphic intergrowth of quartz and a few flakes of biotite. Some are euhedral. Others are rounded or angular. In detail the boundaries of all crystals are irregular (Plate XX, 3) and suggest partial resorption of the crystals by the matrix. One crystal noted is probably a Baveno twin. The two tourmaline pegmatites, other than the "porphyritic" tourmaline pegmatite, consist essentially of graphic intergrowths of potassium feldspar and quartz. One contains pink potassium feldspar and has accessory biotite; the other contains white potassium feldspar and has accessory muscovite and a trace of biotite. Contacts of the former pegmatite are not exposed, but the latter is cross-cutting and has a chilled marginal zone about one-half inch wide (Plate XX, 2). Tourmaline crystals are concentrated near the contact and are, in general, aligned perpendicular to it.

UNIT (15) VEIN QUARTZ

Giant quartz veins occur in the Sandfly Lake Area on the west side of

Pikoos Island; about one-half mile west of Pipikos Bay; and on two small islands north of Pikoos Island. A swarm of smaller veins, as much as 200 feet wide, occurs 1/2 mile west of Sandfly Lake.

The quartz veins consist of coarse, milky-white quartz and minor glassy grey quartz, both with a rough, irregular, weathered surface. There is generally both a sub-parallel alignment and segregation of impurities, particularly mica and opaque minerals. There is widespread iron staining in various shades of reddish brown and dark brown, which locally gives the rock the appearance of rose quartz. In a few places in the Pikoos Island vein the normal quartz is cut by narrow elongate lenses of clear quartz parallel to the normal foliation trend. These may be a second generation of quartz or a recrystallized part of the original vein.

Several thin sections of this rock type were examined. In the least deformed there is a mosaic of large quartz grains which generally have smooth mutual boundaries. Undulatory extinction, although present, is weak. This thin section contains interstitial sillimanite and lacks mica. With more deformation, the undulatory extinction becomes stronger (Plate XXI, 1, 2, 3) and the quartz grains become smaller and more intricately sutured. With still more deformation (Plate XXI, 4) a fine granulated aggregate of quartz results. The quartz grains contain a fine dusting of bubbles (except in the final stage) and opaque minerals. These inclusions are concentrated in streaks. Occasional larger grains of muscovite, biotite, opaque minerals, zircon, apatite, and sphene are present, in general interstitial to the quartz grains but in part within them. Although potassium feldspar was not noted in thin section, ir occurs sporadically near the contacts of the quartz veins as small pink grains.

The eastern contact of the Pikoos Island vein was the only one seen. Here this quartz vein contains silicified coarse and fine-grained feldspathic inclusions that seem to have been derived from pegmatite and granitic rocks respectively. The vein quartz probably permeates the granitic rocks to the east as they are characterized by the presence of numerous patches and streaks of quartz.

Several inclusions of muscovite-sillimanite-magnetite schist were noted in the quartz vein west of Pipikos Bay (Plate XXI, 5, 6). Magnetite crystals up to 1/2 inch in diameter and forming up to an estimated 40 per cent of the rock occur in these inclusions. The largest inclusion that was seen has an exposed width of 10 feet and a length of probably no more than a few hundred feet.

Chapter IV

ORIGIN OF THE METAMORPHOSED AND INTRUSIVE ROCKS

The metamorphosed rocks

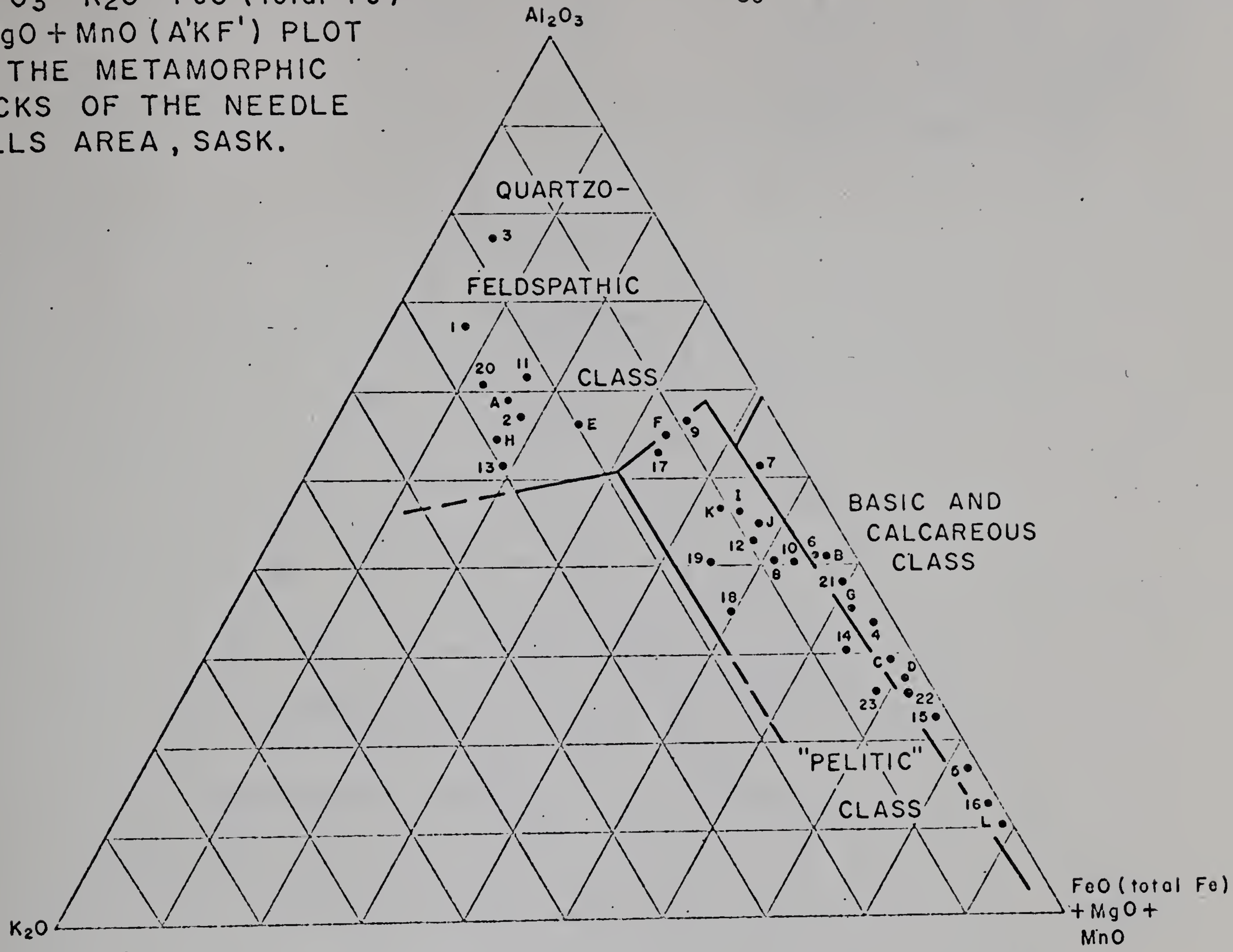
INTRODUCTION

The purpose of this section is to consider the origin of the metamorphic rocks described in Chapter II and to infer as much as possible concerning their depositional environments. In the thesis area both mineralogy and textural features are due mainly to metamorphism, and hence chemical composition becomes a very important guide in determining the origin of rocks. All analysed samples of metamorphic rocks are plotted on Figures 3 and 4, except for some quartzites belonging to unit 8. On these figures, the samples are divided into three classes. The basic and calcareous class includes basic and intermediate igneous rocks and limestone; the "pelitic" class includes subgreywacke, greywacke, and pelites; and the quartzo-feldspathic class includes acidic igneous rocks and arkose. On Figure 3 the boundaries of each class have been set up to include the appropriate "average rocks" within it, and to include samples 9, 10, 14 and 17 in the "pelitic" class. The bulk composition of these samples except 9 (and possibly 10) precludes derivation from igneous rocks, arkose, or limey rocks. The classification of samples 9 and 10 will be further considered in the following discussion. The boundaries on Figure 4 were obtained by grouping rocks which fall in a class on Figure 3 in the same class on Figure 4 with one exception (sample 23) which will be discussed later.

In the following sections chemical composition is considered in more detail and is used, in conjunction with other evidence, to determine the depositional environments of the metamorphic rocks. For purposes of discussion, these have been divided into five sub-divisions, the "older metamorphic rocks" and petrolog-

FIGURE 3

$Al_2O_3 - K_2O - FeO$ (total Fe) $+ MgO + MnO$ (A'KF') PLOT OF THE METAMORPHIC ROCKS OF THE NEEDLE FALLS AREA, SASK.



——— Assumed boundary of class — — —Approximate boundary of class

SAMPLES, NEEDLE FALLS AREA

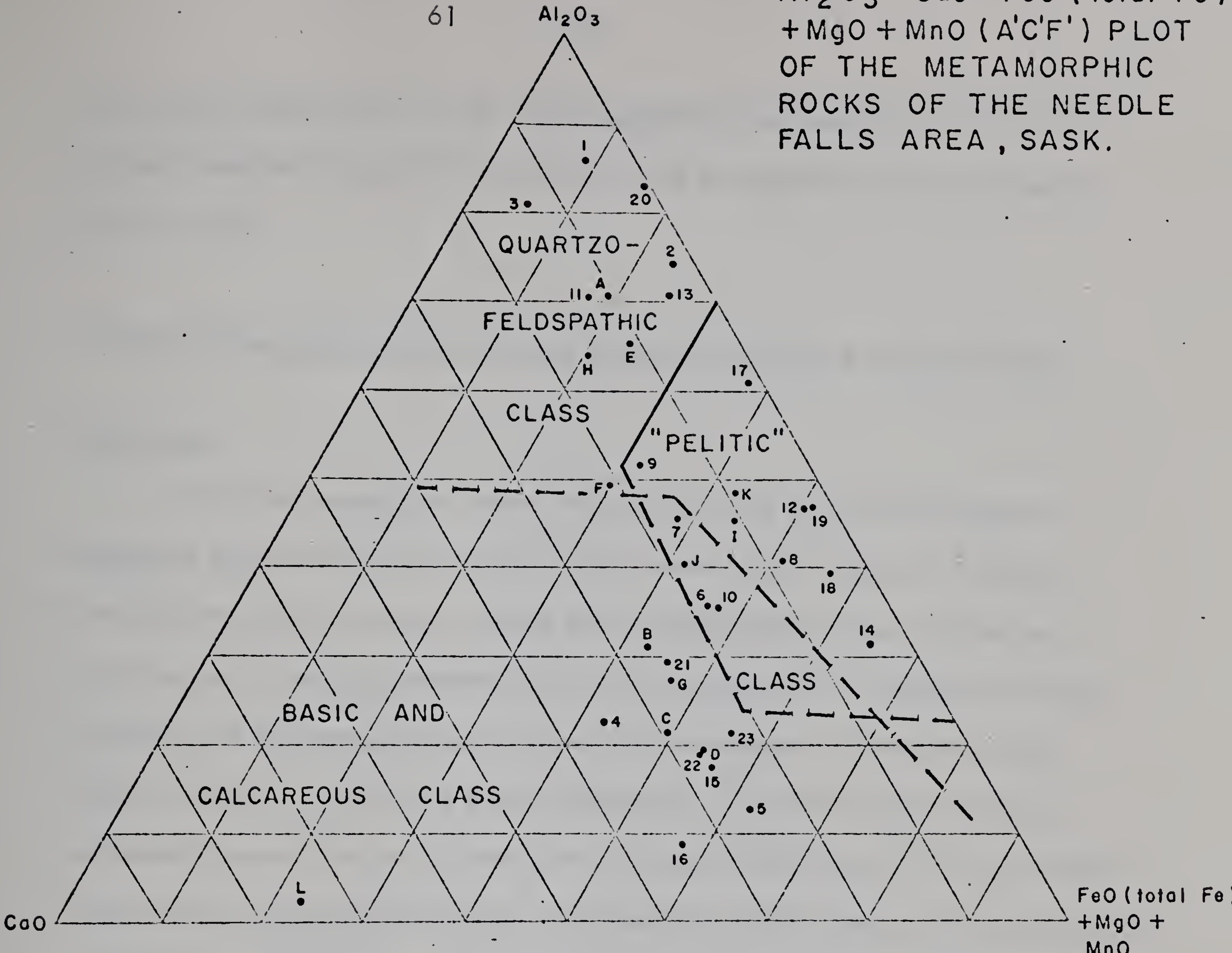
1. Map unit (1?), #614-30-8a
2. Map unit (1), #614-40-8a
3. Map unit (1), #614-40-8b
4. Map unit (5), #614-41-9
5. Map unit (2), #624-67-9a
6. Map unit (2), #614-24-12
7. Map unit (2), #614-63-4
8. Map unit (3a), #624-81-5
9. Map unit (3b), #634-52-1
10. Map unit (3b), #624-56-15
11. Map unit (4), #614-67-3
12. Map unit (5), #614-19-1c
13. Map unit (5), #614-19-7
14. Map unit (5), #624-Y-7
15. Map unit (6a), #614-89-4
16. Map unit (6b), #624-Y-3
17. Map unit (9), #614-46-9
18. Map unit (9), #624-84-6
19. Map unit (9), #614-25-7
20. Map unit (8), #624-24-9
21. Map unit (10), #614-27-1
22. Map unit (2), #614-64-10
23. Map unit (2), #614-36-5

STANDARD SAMPLES (AVERAGE ROCKS)

A. Calc-alkali rhyolite (Nockolds, 1954)
B. Andesite (Nockolds, 1954)
C. "Normal" tholeiite (Nockolds, 1954)
D. "Normal" alkali basalt (Nockolds, 1954)
E. Calc-alkali granite (Nockolds, 1954)
F. Granodiorite (Nockolds, 1954)
G. Diorite (Nockolds, 1954)
H. Arkose (Pettijohn, 1949)
I. Subgreywacke (Pettijohn, 1949)
J. Greywacke (Pettijohn, 1949)
K. Pelite (Shaw, 1956)
L. Limestone (Green, 1959)

FIGURE 4

$Al_2O_3 - CaO - FeO$ (total Fe) $+ MgO + MnO$ (A'C'F') PLOT OF THE METAMORPHIC ROCKS OF THE NEEDLE FALLS AREA, SASK.



——— Assumed boundary of class   — — —Approximate boundary of class

SAMPLES, NEEDLE FALLS AREA

1. Map unit (1?), #614-30-8a
2. Map unit (1), #614-40-8a
3. Map unit (1), #614-40-8b
4. Map unit (5), #614-41-9
5. Map unit (2), #624-67-9a
6. Map unit (2), #614-24-12
7. Map unit (2), #614-63-4
8. Map unit (3a), #624-81-5
9. Map unit (3b), #634-52-1
10. Map unit (3b), #624-56-15
11. Map unit (4), #614-67-3
12. Map unit (5), #614-19-1c
13. Map unit (5), #614-19-7
14. Map unit (5), #624-Y-7
15. Map unit (6a), #614-89-4
16. Map unit (6b), #624-Y-3
17. Map unit (9), #614-46-9
18. Map unit (9), #624-84-6
19. Map unit (9), #614-25-7
20. Map unit (8), #624-24-9
21. Map unit (10), #614-27-1
22. Map unit (2), #614-64-10
23. Map unit (2), #614-36-5

STANDARD SAMPLES (AVERAGE ROCKS)

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I. Subgreywacke (Pettijohn, 1949)
J. Greywacke (Pettijohn, 1949)
K. Pelite (Shaw, 1956)
L. Limestone (Green, 1959)

ically similar rocks (units 1 to 4), the "cordierite-garnet rocks" (unit 5), the pyroxene amphibolites (unit 6), the Meyers Lake Group (units 7 to 9), and epidiorite (unit 10).

"OLDER METAMORPHIC ROCKS" AND PETROLOGICALLY SIMILAR ROCKS

Introduction

The "older metamorphic rocks" and similar rocks fall into the quartzo-feldspathic class (meta-arkose, acidic meta-volcanic (?) rocks), the "pelitic" class (biotite schist and gneiss, knobby biotite-plagioclase gneiss) and the basic and calcareous class (hornblende-biotite rocks, amphibolite). These are discussed in order in the following sections and then the environment of deposition of the "older metamorphic rocks" as a group is discussed. The informal group "older metamorphic rocks" consists of those rocks included in map-units (1) to (4) inclusive which occur in the eastern fold belt. Petrologically similar rocks which occur outside of this belt and that have been included in map-units (2) and (3) are of uncertain relationship to the "older metamorphic rocks".

Quartzo-feldspathic class

This class includes rocks mapped as meta-arkose and as acidic meta-volcanic(?) rocks. Such rocks are confined to the eastern fold belt and hence by definition belong to the "older metamorphic rocks". The composition of analysed samples and of the appropriate standard rocks are given in Table II.

Table II: Chemical analyses of quartzo-feldspathic rocks belonging to the "older metamorphic rocks", of a petrologically similar rock, and of standard rocks.

Sample Number and Classification

	614-30-8a[1] Meta-arkose	614-40-8a Meta-arkose	614-40-8b Cobble from meta-arkose	614-67-3 Acidic meta-volcanic (?) rock
SiO_2	73.6	75.0	72.5	72.7
TiO_2	0.06	0.21	0.08	0.23
Al_2O_3	19.37	14.03	16.48	14.98
Fe_2O_3	1.57	2.11	0.97	1.57
MnO	0.01	0.03	0.01	0.03
MgO	--	0.7	--	0.7
CaO	0.04	0.20	1.44	1.44
Na_2O	0.83	1.18	5.32	3.90
K_2O	6.91	5.65	3.36	4.93
Total	102.4	99.1	100.2	100.5

	Average arkose[2]	Average calc-alkali rhyolite[3]	Average calc-alkali granite[4]	Western granitic rock (Unit 12) Average of 3
SiO_2	76.1	74.2	72.5	72.3
TiO_2	--	0.2	0.4	0.3
Al_2O_3	11.5	13.6	13.9	16.2
Fe_2O_3	2.4	2.2	2.8	2.9
MnO	0.2	--	0.1	0.1
MgO	0.1	0.3	0.5	--
CaO	1.6	1.1	1.3	0.9
Na_2O	2.0	3.0	3.1	3.7
K_2O	5.7	5.4	5.4	5.7
Total				102.0

[1] From immediately below the quartz-pebble conglomerate belonging to the Meyers Lake Group. Stratigraphic position of this sample is uncertain.
[2] Pettijohn, 1949, p. 259
[3] Nockolds, 1954, p. 1012
[4] Nockolds, 1954, p. 1012

The sedimentary origin of the meta-arkose is indicated by the presence of contained cobbles and boulders. It is confirmed by the CaO and Na_2O contents of the analysed samples, both too low for an igneous origin. A feature of interest is the unusually low CaO content and CaO : Na_2O of these rocks as compared to the average arkose. This finds a parallel in the CaO content and CaO : Na_2O ratio of the western granitic rocks, which is lower than that of the average granite. It is suggested that the meta-arkose may be derived at least in part from the western granitic rocks. If the muscovite content of the meta-arkose is considered to be re-crystallized matrix, the analysed samples and all samples (except one) for which modal analyses were made are feldspathic greywacke (Pettijohn, 1949) or arkosic wacke (Gilbert _in_ Williams, Turner and Gilbert, 1955) rather than arkose or arkosic arenite. If the muscovite is not re-crystallized matrix, it presumably was derived from the breakdown of K-feldspar during metamorphism. Possible reactions are:

(1) 2 K-feldspar + 1 kaolinite = 1 muscovite + 4 quartz + 2 water

(2) 2 K-feldspar + 2 anorthite + 2 water = 1 muscovite + 4 quartz + 2 CaO

The first reaction results in a higher proportion of combined quartz and feldspar and lowers the apparent percentage of matrix minerals. If the second reaction had taken place there must have been an almost quantitative removal of CaO during metamorphism. The presence of cobbles within the meta-arkose with "normal" CaO contents provides evidence against this. It seems likely, therefore, that these rocks were feldspathic greywacke or arkosic wacke. The writer prefers Gilbert's term (arkosic wacke) for such rocks.

On the basis of their chemical composition the samples of the acidic meta-volcanic (?) rocks and of a cobble from the meta-arkose must have been either arkoses or acidic igneous rocks originally. In the case of the cobble from the meta-arkose, the analysed sample differs from the arkosic matrix in that it contains much more CaO and Na_2O and somewhat less K_2O (Table II). Its

composition is one which probably could be expected in an igneous rock (see Table III which follows).

Table III: Composition, C.I.P.W. classification and partial mode of a cobble (sample 614-40-8b) from the meta-arkose.

SiO_2	72.5	Q	25.4			Quartz	26
TiO_2	0.08	or	19.79	71.84F	sal.	K-feldspar	22
Al_2O_3	16.48	ab	44.91		98.7	Plagioclase	48
Fe_2O_3	0.97	an	7.14			(An content)	(15)
MnO	0.01	C	1.50			Muscovite	2
MgO	--					Biotite	1
Cao	1.44	hy	0.66			Opaques	1
Na_2O	5.32	mt	0.51		fem. 1.32		
K_2O	3.36	il	0.15				
Total	100.2	Total	100.00				

C.I.P.W. classification: 1.4.2.4.

Washington (1917) lists 203 analyses which fall into this subdivision of the C.I.P.W. classification, mainly classified as granite, granodiorite, rhyolite, trachyte, andesite and dacite. On the basis of William's classification (Williams, Turner, and Gilbert, 1955, p. 121) this sample, if igneous, was originally a dacite or granodiorite, although close to the rhyodacite-adamellite (quartz monzonite) category. In view of the uncertainty with regard to how much of the albite may have originally been intergrown with the K-feldspar as a perthite (thus increasing the K-feldspar content), and the sodic nature of the plagioclase, this sample is preferably classed as having been rhyodacite or adamellite if originally igneous. Na-metasomatism is ruled out as a major factor in determining plagioclase composition on the basis of the low Na content of the enclosing meta-arkose. The fact that this sample does have a fairly normal igneous composition strongly suggests, but does not prove, that it is of igneous origin. It would conceivably be a cobble of an older arkose which had a normal igneous composition.

The boulders and other cobble for which modal analyses were made (Table XXVI) originally were rhyodacite or adamellite (quartz monzonite) if of igneous origin. They each contain about 50 per cent of modal quartz, however, which is high for an igneous rock, although such rocks are known (Washington, 1917; p. 63, 69, 71, 83, 89). If the pebbles, cobbles, and boulders were part of an older arkose (the alternative origin) some of the larger ones might be expected to show some layering, and the grain size of different cobbles would be expected to be fairly uniform. No evidence of layering was seen, and the cobbles vary in grain size from very fine-grained aplitic-appearing rocks to those with a medium-grained granitic appearance. In part the finer-grained rocks owe their present textures to cataclasis, but the writer is convinced that real differences in original grain size existed. Evidence for this is shown in Plate 1, 1. It is most difficult to imagine a mechanism whereby the cobble in the upper left of this plate derived its extremely fine grain size through cataclasis without the adjacent boulder being affected.

The writer feels that, in the absence of any definite evidence that the cobbles were arkoses, and with evidence that some at least were igneous, they can be considered to be of igneous origin. On the basis of grain size some were undoubtedly plutonic. The finer-grained varieties may have been granitic and/or aplitic dykes and/or acidic volcanic rocks.

The C.I.P.W. norm, chemical composition and partial mode of the analysed sample (614-67-3) of the acidic meta-volcanic (?) rocks are given in Table IV.

Table IV: Composition, C.I.P.W. classification and partial mode of a sample (614-67-3) of acidic meta-volcanic (?) rocks (unit 4)

SiO_2	72.7	Q	27.7		sal. 97.4	Quartz	27
TiO_2	0.23	or	29.09	69.17F		K-feldspar	23
Al_2O_3	14.98	ab	32.91			Plagioclase	41
Fe_2O_3	1.57	an	7.17			(An content)	(17)
MnO	0.03	C	0.61			Biotite	8
MgO	0.7						
CaO	1.44	hy	1.7		fem. 3.5		
Na_2O	3.90	mt	1.39				
K_2O	4.93	il	0.43				
Total	100.5	Total	101.0				

C.I.P.W. classification: 1.4.2.3.

Washington (1917) lists 381 analyses which fall into this subdivision of the C.I.P.W. classification, almost all listed as granite, rhyolite, or trachyte, so the sample is probably of normal igneous composition. If of igneous origin, this sample would have been a rhyodacite in Williams's classification (Williams, Turner and Gilbert, 1955, p. 121). Other samples for which modal analyses were carried out (Table XXIX) have the composition of rhyodacite (samples 624-21-5b; 614-95-4) or dacite (sample 624-88-3). The normal igneous composition of sample 614-67-3 strongly suggests an igneous rather than an arkosic origin. Further evidence for an igneous origin for these rocks is the much higher CaO and Na_2O content and the much finer grain size of the acidic meta-volcanic (?) rocks compared to the meta-arkose. The acidic meta-volcanic (?) rocks and the meta-arkose are both interlayered with the hornblende-biotite rocks and hence if both were sedimentary they would presumably have formed in similar environments. If this were the case it would be expected that the acidic meta-volcanic (?) rocks, being finer-grained, would have a lower percentage of plagioclase than the meta-arkose and hence lower CaO and Na_2O. Other features suggesting an igneous origin for the acidic meta-volcanic

(?) rocks are their rusty weathering, close jointing, and almost conchoidal fracture. It is suggested that the massive rocks belonging to this unit are derived from volcanic flows and that the thinly layered rocks (Plate V, 1) are derived from fine-grained tuffaceous rocks, unless the layering is a form of flow banding.

"Pelitic" class

Analysed samples of rocks belonging to the "older metamorphic rocks" and a petrologically similar rock which were placed in the "pelitic" class on Figure 3 are shown in Table V, except for sample 614-36-5 (Figures 3 and 4, #23). This sample (an amphibolite) is discussed with the rocks of the "basic and calcareous" class as in most respects it resembles a basic rock.

Table V: Chemical analyses of "pelitic" rocks belonging to the "older metamorphic rocks", of a petrologically similar rock, and of standard rocks.

	Sample Number and Classification			
	624-81-5 knobby biot.-plag. gneiss	634-52-1[1] biotite gneiss	624-56-15 biotite gneiss	Average high grade pelite[2]
SiO_2	62.6	68.6	66.7	65.01
TiO_2	0.59	0.34	0.45	0.82
Al_2O_3	15.46	15.69	13.46	17.84
Fe_2O_3	4.96	3.26	5.38	7.38
MnO	0.08	0.03	0.10	--
MgO	5.2	2.1	4.0	2.38
CaO	1.60	2.64	3.44	1.27
Na_2O	4.41	3.20	3.76	2.00
K_2O	2.99	2.34	1.93	3.43
Total	97.9	97.3	99.1	

Table V continued

	Average greywacke[3]	Average subgreywacke[3]	Average granodiorite[4]	Average rhyodacite[4]
SiO_2	65.8	78.9	66.88	66.27
TiO_2	0.5	0.6	0.57	0.66
Al_2O_3	14.4	9.6	15.66	15.39
Fe_2O_3	5.7	3.9	4.18	4.59
MnO	0.1	0.2	0.07	0.07
MgO	3.0	1.6	1.57	1.57
CaO	3.6	1.2	3.56	3.68
Na_2O	3.5	2.1	3.84	4.13
K_2O	2.1	1.5	3.07	3.01

[1] A petrologically similar rock, which, unlike the other analysed samples, does not not belong to the "older metamorphic rocks".
[2] Shaw (1956, p. 929)
[3] Pettijohn (1949, p. 256)
[4] Nockolds (1954, p. 1014)

The three remaining samples are in most respects well within the compositional range to be expected for the sedimentary rocks grouped in the "pelitic" class (greywacke, subgreywacke, and true pelites) but also show varying degrees of chemical similarity to intermediate igneous rocks (granodiorite, rhyodacite, tonalite, and dacite). The problem of determining whether a sedimentary or igneous origin is more likely for these rock samples is complicated by the possibility that they may have undergone K-metasomatism (see unit 11, this chapter), Mg-metasomatism (see anthophyllite-cordierite-biotite gneiss, this chapter), and albitization of plagioclase (see the following section on the "basic and calcareous class"). Despite this complication, the writer thinks that the chemical evidence is definitely in favour of a sedimentary origin for two of the samples (624-81-5, 624-56-15). The third sample (634-52-1) is about equally close in composition to the average greywacke and to the average granodiorite or rhyodacite (Table V) and hence may have been either sedimentary or igneous. If related to the other two samples it presumably has the same origin as these samples.

To substantiate the statement that the chemical evidence is in favour of a sedimentary origin for samples 624-81-5 and 624-56-15, the effects on these samples of K-metasomatism, Mg- and Fe-metasomatism, and albitization of plagioclase will be examined with the aid of Figures 3 and 4. If it is assumed that both samples have undergone K-metasomatism, their positions on Figure 3 (before metasomatism) can be found by projecting them away from the K_2O corner. If this is done both samples would be projected near the average andesite. However, both contain far too much SiO_2 to be derived from andesite. Assume that both samples have undergone albitization of plagioclase and project both towards the CaO-corner on Figure 4. The igneous rocks they can be brought into coincidence with is again andesite. Assume that both samples have undergone Mg-metasomatism and project them away from the FeO+MgO+MnO corner on Figures 3 and 4. On both figures, sample 624-56-15 may be brought into near coincidence with the average granodiorite only by assuming considerable Mg-metasomatism. This sample can be brought into near coincidence with the average greywacke by assuming much less metasomatism. Sample 624-81-5 can only be brought into coincidence with an igneous rocks by assuming that it has been considerably affected by both albitization and Mg-metasomatism; it may be brought into coincidence with the average greywacke by assuming less albitization and less Mg-metasomatism. Further evidence for the non-igneous origin for sample 624-56-15 is provided by its Al_2O_3- and K_2O contents, both decidedly low for an igneous rocks whose SiO_2- content is that of an average granodiorite or rhyodacite (Table V). To summarize; (1) the present composition of samples 624-56-15 and 624-81-5 could be produced by much less metasomatism of greywacke than of an igneous rock and hence derivation from a greywacke is more likely; (2) chemical features in sample 624-56-15 which are unlikely to be due to metasomatism (Al_2O_3- and K_2O- content) are not appropriate for an igneous rock and hence indicate a sedimentary origin.

The writer accepts that sample 624-56-15, 624-81-5, and 634-52-1 (if related to the other samples) are probably of sedimentary origin and that the map-unit which they are derived from is probably predominantly of sedimentary

origin. In the preceding discussion it has been assumed that, if sedimentary, these samples were derived from greywacke. The feature which distinguishes greywacke (and subgreywacke) from true pelites is the $Na_2O:K_2O$ ratio. Middleton (1960) has shown that eugeosynclinal sandstones, which (Middleton, 1960, p. 1017) "are in fact.....the greywackes of Pettijohn (1957) "rarely have weight per cent $Na_2O:K_2O$ ratios of less than 1.0. The arithmetic mean for this ratio in eugeosynclinal sandstones is 1.6 (Middleton, 1960). It is 1.7 and 1.4 for greywacke and subgreywacke respectively (Pettijohn, 1949). The average ratios for high and low grade pelites are 0.59 and 0.49 respectively (Shaw, 1956) and the standard deviations of Na_2O and K_2O contents for pelites are small enough that only a decidedly aberrant pelite would have an $Na_2O:K_2O$ ratio of more than 1.0. The analysed samples 624-81-5, 634-52-1, and 624-56-15 have $Na_2O:K_2O$ ratios of 1.47, 1.37, and 1.95 respectively, putting them in the greywacke-subgreywacke class. These ratios could be affected by albitization of plagioclase but as all three samples contain more CaO than the average pelite (Table V) and two of them have $Na_2O:CaO$ ratios which are less than that of the average pelite, albitization of a pelite almost certainly could not produce these $Na_2O:K_2O$ ratios. The SiO_2 and Al_2O_3 content of these rocks indicates that they were greywacke (if sedimentary) and not subgreywacke.

Basic and calcareous class

Four analysed samples fall in this class. Another sample, 614-36-5, although it falls in the "pelitic" class on Figure 3, is much more similar to a basic rock than a "pelitic" rock in most respects and hence is included in the basic and calcareous class for purposes of discussion. Analyses and C.I.P.W. norms for the analysed samples and for appropriate average rocks are shown in Table VI.

Table VI: Chemical analyses and modified C.I.P.W. norms of basic and calcareous rocks belonging to the "older metamorphic rocks", of petrologically similar rocks, and of standard rocks.

	614-24-12 Hrn.-biot. gneiss	614-63-4 Hrn.-biot. gneiss	614-36-5 Amphibolite	614-64-10 Amphibolite	624-67-9a[1] Amphibolite
SiO_2	57.8	69.0	47.2	41.5	47.6
TiO_2	0.91	0.35	0.76	1.32	0.53
Al_2O_3	17.02	13.79	14.49	14.78	9.94
Fe_2O_3	6.59	3.79	13.01	13.54	10.16
MnO	0.08	0.06	0.23	0.15	0.21
MgO	5.5	2.7	9.8	7.8	14.1
CaO	4.7	2.75	8.09	11.68	10.86
Na_2O	4.52	4.08	2.90	1.85	0.97
K_2O	1.43	1.03	3.00	1.48	0.58
Total	98.6	97.6	99.4	94.1	95.0
Q	6.8	29.8	--	--	--
or	8.5	6.1	17.7	8.7	3.4
ab	38.2	34.4	13.1	5.8	8.2
an	22.0	13.7	17.4	27.7	21.1
ne	--	--	6.4	5.6	--
C	--	1.0	--	--	--
$CaSiO_3$	0.6	--	9.0	12.5	13.7
$MgSiO_3$	13.6	6.7	5.9	8.0	34.4
$FeSiO_3$	2.7	3.6	2.4	3.8	8.8
Mg_2SiO_4	--	--	12.8	7.8	3.7
Fe_2SiO_4	--	--	5.7	4.2	5.9
mt	2.1	1.2	9.5	9.9	3.3
il	2.2	0.7	1.4	4.0	1.0

Table VI continued

	Average alkali basalt[2]	Average dacite[3]	Average andesite[4]	Average greywacke[5]
SiO_2	45.78	63.58	54.20	65.8
TiO_2	2.63	0.64	1.31	0.5
Al_2O_3	14.64	16.67	17.17	14.4
Fe_2O_3	12.76	5.54	9.43	5.7
MnO	0.20	0.11	0.15	0.1
MgO	9.39	2.12	4.36	3.0
CaO	10.74	5.53	7.92	3.6
Na_2O	2.63	3.98	3.67	3.5
K_2O	0.95	1.40	1.11	2.1
Q	--	19.6	5.7	
or	6.1	8.3	6.7	
ab	18.3	34.1	30.9	
an	24.7	23.3	27.2	
ne	2.3	--	--	
C	--	--	--	
$CaSiO_3$	10.8	1.3	4.2	
$MgSiO_3$	7.1	5.3	10.9	
$FeSiO_3$	2.9	2.8	5.3	
Mg_2SiO_4	11.5	--	--	
Fe_2SiO_4	5.0	--	--	
mt	4.6	3.3	5.1	
il	5.0	1.2	2.4	

[1] A petrologically similar rock which, unlike the other analysed samples, does not belong to the "older metamorphic rocks".
[2] Nockolds (1954), p. 1021
[3] Nockolds (1954), p. 1015
[4] Nockolds (1954), p. 1019
[5] Pettijohn (1949), p. 256

The two samples of hornblende-biotite gneiss (614-24-12: 614-63-4) have compositions which are within the range reported for intermediate igneous rocks. In the C.I.P.W. classification sample 614-24-12 falls in Class II, Order 5, Rang 3, Subrang 4. In Washington's compilation (1917, p. 479-526) there are 329 analyses which fall in this group. Only four of these analyses (99, 113, 157, 179) closely resemble sample 614-24-12 and all four are of quite unusual rocks which are characterized by an unusually high ab:an ratio for rocks of their normative quartz (Q) content. Two of these samples are described as andesite, one as diorite, and one as tonalite.

In comparison with the average dacite and andesite (see Table VI) sample 614-24-12 is intermediate between the two in its content of SiO_2, TiO_2, Al_2O_3, and Fe_2O_3, but higher than both in MgO, Na_2O, and K_2O and lower in CaO. The sum of Na_2O + CaO in sample 614-24-12 is intermediate between the sums of the same elements in the average dacite and andesite and the low CaO and high Na_2O could be due to partial albitization. The high MgO and K_2O contents may be due to Mg- and K- metasomatism, as other rocks occurring within the eastern fold belt provide evidence that both have occurred. To summarize, at present sample 612-24-12 has the composition of a rather unusual intermediate igneous rock. However, the unusual features could be due to metasomatism and this sample's original composition could have been between those of the average andesite and average dacite. The writer thinks that sample 614-24-12 may have been derived from an igneous rock and that if so it was originally an intermediate (andesite-dacite) volcanic rock or possibly a tuff.

Another possibility worth considering is that sample 614-24-12 is derived from greywacke. As Table VI shows, the chemical resemblance between this sample and the average greywacke is not marked. Pettijohn (1957, p. 306) tabulates 13 analyses of greywacke. Twelve of the 13 are markedly higher than sample

614-24-12 in SiO_2 and differ considerably from it in one or more other oxides including, in most cases, Al_2O_3. The only greywacke ("K") close to sample 614-24-12 in SiO_2 content (on an H_2O- and CO_2-free basis) and somewhat similar in other oxides is from the Miocene of Papua and, as Pettijohn (1957, p. 303) remarks, "...the Miocene greywackes of Papua...are undoubtedly contaminated with or derived from basic tuffs." In view of the complete re-crystallization which the hornblende-biotite gneiss has undergone and the possibility of metasomatism it must remain an open question whether this particular sample (614-24-12) was originally a volcanic rock, a tuff, or a greywacke derived from or contaminated by volcanic rocks, but one of these origins seems likely. In any case, this sample provides definite evidence that volcanism was going on near by during the time of deposition of the "older metamorphic rocks".

Sample 614-63-3, the other analysed sample of hornblende-biotite gneiss, has a norm that is very similar to Washington's (1917, p. 340, 389) analyses #145 and #228 in subdivision II.4.3.4., both described as quartz diorite. The norms of sample 614-63-4 and of #145 and #228 are characterized by exceptionally high ab:an ratios like the norms of sample 614-24-12 and similar rock types. This may indicate either that samples 614-63-4 and 612-24-12 are genetically related or that both have undergone albitization. The texture of sample 614-63-4 (Plate III, 3,4), its field occurrence (a few feet from a contact with meta-arkose) and its decidedly aberrant quartz-rich composition as compared with the hornblende-biotite rocks in general (Table XXVII) suggest that it has been contaminated by a quartz-rich (arkosic?) material and it is inferred that this sample may have been tuffaceous.

The two samples (614-36-5, 614-64-10) of amphibolite which belong to the "older metamorphic rocks" have compositions which are in most respects within the range reported for basic igneous rocks. Sample 614-36-5 is quite similar to the average alkali basalt (Table VI) and, in fact, falls well within the range

for alkali basalts and similar rocks (Washington, 1917, p. 605-631) except for abnormally high K_2O. This feature may be due to K-metasomatism. Sample 614-64-10 is also similar to the average alkali basalt. The reported SiO_2 content is unusually low but alkali basalts with SiO_2 in this range and otherwise resembling this sample have been previously reported (Washington, 1917, p. 656, #133 to 136 inclusive). Both samples, therefore, may have originally been basaltic igneous rocks. The only other possible source rocks (unless these rocks have undergone extreme metasomatism) are limey argillite or limey greywacke. Calculations show that adding enough CaO and MgO to the average pelite or greywacke to approximate the CaO and MgO contents of samples 614-36-5 and 614-64-10 results in rocks containing nearly 60 per cent or more of SiO_2 and only about 5 to 7 per cent Fe_2O_3. Therefore, derivation of these samples from a limey argillite or greywacke is considered to be unlikely. If such was their origin, it is most extraordinary that CaO was not at least locally sufficiently abundant to produce calc-silicate minerals such as actinolite and diopside, both absent in the amphibolites of the eastern fold belt although occurring elsewhere in the thesis area.

Sample 624-67-9a is an unusually mafic amphibolite from a small, unmappable body completely surrounded by granitic rocks. It falls in subdivision IV. 1.1.2.2. in the C.I.P.W. classification. As there are no examples of this subdivision in Washington's (1917) compilation, it is apparent that this amphibolite does not have the composition of a normal igneous rock. Its composition is also inappropriate for a CaO - pelite (or reywacke) mixture. It must be concluded that this sample is of uncertain origin and has probably undergone considerable metasomatism. This sample was analysed in an attempt to see whether it was more likely to be a meta-volcanic rock (like the amphibolites of the "older metamorphic rocks") or a calc-silicate rock (like certain amphibolites and similar rocks to be described).

Depositional environment of the "older metamorphic rocks"

The "older metamorphic rocks" consist of map units 1, 2 (in part), 3a, 3b (in part), and 4. The classification of the rocks belonging to these units is summarized below:

> Unit (1): The predominant rock type consists mainly of quartz, potassium feldspar, and muscovite. If the muscovite is derived from a clay mineral matrix this map unit was originally mainly feldspathic greywacke (Pettijohn's classification) or arkosic wacke (Gilbert's classification). Chemically this rock type is arkose and not greywacke. Sparse pebbles, cobbles, and boulders of acidic igneous rocks occur in the predominant rock type.
>
> Unit (2): Two analysed samples of amphibolite were probably originally alkali basalt. Two analysed samples of hornblende-biotite rocks were probably originally intermediate volcanic rocks or tuffs, or greywacke derived from volcanic material.
>
> Unit (3): Two analysed samples belonging to the "older metamorphic rocks" were probably originally greywacke.
>
> Unit (4): This unit probably consisted mainly of acidic volcanic rocks (rhyodacite, dacite), and probably in part of acidic tuffaceous rocks.

Pettijohn (1957, p. 610) has set up a classification which divides consanguineous associations of sedimentary rocks (and associated volcanic rocks) into four suites, the greywacke suite, the subgreywacke suite, the orthoquartzite-carbonate suite, and the arkosic suite. The "older metamorphic rocks" show little or no lithological resemblance to the subgreywacke or orthoquartzite-carbonate suites and cannot belong to either. The arkosic suite is terrestrial and deposition occurs in fluvial, lacustrine, and paludal environments (Pettijohn, 1957, p. 610). The characteristic sedimentary rock types are arkoses (in a broad sense, see Pettijohn, 1957, p. 629), lithic arenites (subgreywacke, protoquartzite), and conglomerates. Diabase sills and dykes commonly occur and volcanic rocks may be present. The "older metamorphic rocks" differ from this suite most importantly in that they contain abundant rocks which appear to have been derived from greywacke (unit 3, perhaps part of unit 2, and most of unit 1 using Pettijohn's (1957) terminology). Greywacke (Pettijohn, 1957, p. 617) is characteristically a product of a marine, relatively deep-water environment and hence the presence of it would seem to preclude the

placing of the "older metamorphic rocks" in the arkosic suite.

The remaining suite, the greywacke suite, is characteristic of a marine, geosynclinal environment (Pettijohn, 1957, p. 615-618; Krumbein and Sloss, 1956, p. 388-389). The predominant sedimentary rock types are greywacke and shale. Volcanic rocks and tuffs (usually basic and commonly spilitic) occur in eugeosynclinal assemblages. The "older metamorphic rocks" differ from this suite in that: (1) no shales have been identified, (2) an abundant rock type ("meta-arkose") is arkose chemically and is probably best described as a metamorphosed arkosic wacke (Gilbert in Williams, Turner, and Gilbert, 1955), and (3) the meta-volcanic rocks are predominantly intermediate to acidic in composition. These features indicate that the "older metamorphic rocks" certainly are not typical of the greywacke suite and hence were probably not deposited in a typical eugeosynclinal environment. The composition of the volcanic rocks and the abundance of arkosic rocks are explainable if the "older metamorphic rocks" were deposited in a geosyncline or intracratonic basin which had a sialic basement. Evidence for the existence of such a basement is provided by the presence of the western granitic rocks (which are probably unconformably overlain by the "older metamorphic rocks"; see Chapter VI). The lack of shale could indicate that the whole of the "older metamorphic rocks" were derived from rapid erosion of coarsely crystalline rocks (so that hardly any shale was formed). It could also indicate that shale was formed but was deposited in a different area than greywacke. If this were the case it would be necessary to postulate deposition in an environment in which much more sorting took place than in the normal geosynclinal environment. Another possibility is that the lack of shale is more apparent than real. Shales could be present but might not be identified if they were originally thinly interbedded with greywacke and if the interbedded sequence was re-crystallized and homogenized during metamorphism.

To summarize the discussion of the depositional environment of the "older metamorphic rocks", this group does not belong to the subgreywacke or ortho-

quartzite-carbonate or arkosic suites of Pettijohn (1957) and differs in several ways from the greywacke suite. The differences from the greywacke suite, with the exception of the apparent absence of shale, are explainable if the group was deposited in an intractatonic basin or geosyncline with a sialic basement. There is good evidence for such a basement. Several possible explanations for the apparent absence of shale are made but not positive conclusions are drawn.

"CORDIERITE-GARNET ROCKS"

Introduction

Within the thesis area the "cordierite-garnet rocks" consist predominantly of cordieritic and/or garnetiferous biotitic rocks, with minor "arkosic" layers and minor plagioclase-scapolite-clinopyroxene rocks and hornblende-biotite-clinopyroxene rocks. Analysed samples fall into all three classes on Figures 3 and 4. These are considered in the following sections.

Quartzo-feldspathic class

Only one analysed sample (614-19-7) from this unit falls into this class. This represents the biotite-poor ("arkosic") interlayers within the biotitic rocks. Percentages of major elements are:

SiO_2	77.5
Al_2O_3	10.03
Fe_2O_3	2.77
MgO	----
CaO	0.32
Na_2O	1.38
K_2O	5.41

The composition is not that of an igneous rock and this rock type appears to be Ca-poor meta-arkose. It differs from the meta-arkose belonging to the "older metamorphic rocks" in that it is considerably lower in Al_2O_3 and mica. It is probable that this rock was originally an arkose (Pettijohn, 1957) or arkosic arenite (Gilbert

in, Williams, Turner, and Gilbert, 1955) as it probably lacked any appreciable clay mineral matrix.

"Pelitic" class

Analysed samples which fall into the "pelitic" class are shown in Table VII. Samples 614-19-1c and 624-Y-7 have Na_2O:K_2O weight per cent ratios of 0.41 and 0.09 respectively, as compared to the ratio of the arithmetic mean of 1.6 for greywacke (Middleton, 1960) and the ratio of 0.59 for the average high grade pelite (Shaw, 1956). This ratio is the criterion which distinguishes between true pelites and greywacke. These rocks appear to be true pelites. The MgO and Fe_2O_3 contents of sample 624-Y-7 differ from those for the average high grade pelite by more than two standard deviations and one standard deviation (Shaw, 1956) respectively. Mg- and Fe-metasomatism have probably affected this rock.

Table VII: Chemical analyses of "pelitic" rocks belonging to the "cordierite-garnet rocks" and of standard rocks.

	Sample Number and Classification			
	614-19-1c Biotite-cordierite-sillimanite-garnet gneiss	624-Y-7 Biotite-cordierite-sillimanite-garnet gneiss	Average high grade pelite[1]	Average greywacke[2]
SiO_2	63.0	51.2	65.01	65.9
TiO_2	1.07	1.58	0.82	0.5
Al_2O_3	18.41	18.16	17.84	14.4
Fe_2O_3	7.65	13.34	7.38	5.7
MnO	0.06	0.36	---	0.1
MgO	4.0	7.9	2.38	3.0
CaO	0.76	1.12	1.27	3.6
Na_2O	1.42	0.30	2.00	3.5
K_2O	3.44	3.27	3.43	2.1
Total	99.8	98.1		

[1]Shaw (1956, p. 929)
[2]Pettijohn (1949, p. 256)

Basic and calcareous class

The plagioclase-scapolite-clinopyroxene rocks and the hornblende-biotite-clinopyroxene rocks, which both form a minor part of the "cordierite-garnet rocks", fall into this class. No samples of the former rock type were analysed. On the basis of its mineralogy it is almost certainly a calc-silicate rocks of sedimentary origin. A modified C.I.P.W. norm is given below for a sample (614-41-9) of the hornblende-biotite-clinopyroxene rocks:

Q	10.0
or	4.0
ab	16.2
an	27.7
$CaSiO_3$	12.8
$MgSiO_3$	20.3
$FeSiO_3$	4.4
mt	1.7
il	0.5

There is no rock in Washington's (1917) compilation which resembles this sample. The inference is that it is not of igneous origin, as is suggested by its plot on the A'C'F' diagram (Figure 4) somewhat towards the C corner. The molecular Mg:Ca ratio of the sample is 0.97, approximately that of dolomite. It is suggested that this rock type was a siliceous and calcareous (dolomitic) sediment, in a very broad sense a marl.

Depositional environment of the "cordierite-garnet rocks"

In the thesis area the "cordierite-garnet rocks" consist predominantly of metamorphosed pelites, with minor meta-arkose and calc-silicate rocks. An analysed sample of meta-arkose is probably arkosic arenite in Gilbert's terminology. Rocks that are correlated with the "cordierite-garnet rocks" by the writer have been studied in the Middle Foster Lake area (Mawdsley, 1957; Froese, 1956) and in the Daly Lake Area, East Half (Money, in preparation). In both areas this group is much

more extensively exposed than in the thesis area and, therefore, these areas provide a better basis for discussion of its environment of formation. Froese (1956, p. 48) interpreted the metamorphic rocks of the Middle Foster Lake area as having originally consisted of shales, greywackes, spilite, and limestone. Both "greywacke" and spilite" were so classified in part on the basis of the presence of albite. The writer does not consider this classification to be necessarily valid, as all of the other rocks in the area have undergone upper amphibolite facies metamorphism. Albite could not have been stable during this metamorphism, and hence it must be a late mineral. Its presence may, therefore, be due to late Na-metasomatism. If the high Na_2O content of the "greywacke" and "spilites" is due to metasomatism, these rocks may have originally been normal pelites and limey sediments respectively. It is concluded that the presence of spilites and greywackes in this area has not been proved.

In the Daly Lake Area, East Half, (Money, in preparation) the predominant rock types appear to be derived from pelites and arkoses (as defined by Pettijohn, 1957, p. 291) but there were minor polymictic arkosic conglomerate, greywacke or subgreywacke, and limey sediments and possibly very minor limestone and intermediate or basic volcanic rocks. The thickness of the group is difficult to estimate but is at least several thousand feet and may be ten or twenty thousand feet.

The following may be inferred concerning the depositional environment of the "cordierite-garnet rocks":

1. deposition took place in close proximity to a landmass or landmasses consisting in part of a variety of granitic rocks (based on the presence of polymictic arkosic meta-conglomerate locally and of abundant meta-arkose).
2. deposition was quite rapid and probably took place in an area of crustal instability rather than on or near a stable craton (presence of abundant arkose and of some greywacke (?)).
3. deposition was at least in part probably marine (presence of great thickness of pelites and of minor limey sediments).
4. volcanism was rare or non-existent (no definitely volcanic rocks known, possibly volcanic rocks are very minor in extent).
5. sedimentation took place in an area at least 400 miles long (see Figure 15, Chapter IX) but of an unkown width.
6. deposition probably took place on a sialic basement (the group probably unconformably overlies the "western granitic rocks"; see Chapter VI).

The lithology of the "cordierite-garnet rocks" and the estimated thickness of the group probably implies deposition in either a geosyncline (or intracratonic basin) or a major rift valley. The known extent of the group and the lack or rarity of volcanism suggest that deposition was not in a rift valley. The "cordierite-garnet rocks" differ from the typical geosynclinal suite (Pettijohn, 1957, p. 610) in that this suite commonly contains little or no arkose. Nevertheless, the group differs even more from the other suites in Pettijohn's (op. cit.) classification.

PYROXENE AMPHIBOLITES

Data for samples of the two types of pyroxene amphibolite and standard rocks are given in Table VIII.

Table VIII: Chemical analyses and modified C.I.P.W. norms of pyroxene amphibolites and of standard rocks.

	Sample Number and Classification			
	614-89-4 Hypersthene amphibolite	624-Y-3 Clinopyroxene amphibolite	Average tholeiitic olivine basalt[1]	Average two pyroxene pyroxenite[2]
SiO_2	45.4	50.9	47.90	51.84
TiO_2	1.98	0.54	1.65	0.32
Al_2O_3	12.46	7.19	11.84	4.47
Fe_2O_3	14.78	9.78	13.10	10.28
MnO	0.21	0.20	0.15	0.14
MgO	8.75	13.6	14.07	21.41
CaO	10.64	15.20	9.29	10.99
Na_2O	1.49	0.87	1.66	0.56
K_2O	0.61	0.48	0.54	0.17
Total	96.3	98.8		

Table VIII. continued on next page.

Table VIII. continued

Q	--	--	--	--
or	3.6	2.8	2.8	1.1
ab	12.6	7.3	14.1	4.7
an	25.5	17.1	23.4	9.2
$CaSiO_3$	11.4	24.3	9.1	18.8
$MgSiO_3$	18.5	33.5	20.5	44.9
$FeSiO_3$	11.2	9.6	7.9	9.4
Mg_2SiO_4	2.2	0.1	10.3	6.0
Fe_2SiO_4	1.5	--	4.4	1.4
mt	4.6	3.1	3.3	3.2
il	3.8	0.9	3.2	0.6

[1] Nockolds (1954), p. 1021
[2] Ibid., p. 1022

Sample 614-89-4 (hypersthene amphibolite) belongs to Class III, Order 5, Rang 4, Subrang 5 in the C.I.P.W. classification. There are 197 analyses in this subdivision in Washington's (1917) compilation but none of these are close to this sample in composition. Of the igneous rocks in Nockold's (1954) compilation only tholeiitic olivine basalt has much resemblance to sample 614-89-4, but there is a very large difference in MgO content (see Table VIII). It is concluded that if the analysis is accurate (note the poor total) the hypersthene amphibolite does not have a normal igneous composition at present and that it is of uncertain origin.

Sample 624-Y-3 (clinopyroxene amphibolite) belongs to Class IV, Order 1, Section 1, Rang 2, Subrang 2 in the C.I.P.W. classification. There are no examples of igneous rocks belonging to this subdivision in Washington's (1917) compilation. The two most similar rocks in Nockold's (1954) compilation are tholeiitic olivine basalt and two-pyroxene pyroxenite. The resemblance is not close in either case, especially with regard to CaO (see Table VIII). The very high CaO content suggests that the clinopyroxene amphibolite was originally a carbonate-silicate sedimentary rock. The molecular Mg:Ca ratio is 1.24 (higher than dolomite) implying that either Mg-silicates were present originally or Mg-metasomatism has taken place.

MEYERS LAKE GROUP

Introduction

Textural features and composition leave no doubt concerning the sedimentary origin of the rocks making up the Meyers Lake Group. The two following sections will discuss the precise classification of the quartzites (quartzo-feldspathic class) and schists ("pelitic" class). This is followed by a section on the environment of deposition of the group.

Quartzo-feldspathic class

Analysed samples belonging to the quartzo-feldspathic class are shown in Table IX.

Table IX: Chemical analyses of quartzo-feldspathic rocks belonging to the Meyers Lake Group and of standard rocks.

	614-46-6 "Pure" quartzite	614-38-5 Calcareous quartzite	614-22-19a Grey feldspathic quartzite	624-24-9 Pink feldspathic quartzite
SiO_2	97.2	89.7	92.2	74.1
TiO_2	0.03	0.19	0.06	0.36
Al_2O_3	2.53	4.78	6.48	17.74
Fe_2O_3	0.59	1.46	0.49	1.49
MnO	0.01	0.03	0.01	0.01
MgO	--	1.6	--	0.6
CaO	0.07	0.82	0.08	0.04
Na_2O	0.07	0.58	0.12	0.15
K_2O	1.18	1.77	2.91	7.31
Total	101.7	100.9	102.3	101.8

	Average orthoquartzite[1]	Average arkose[2]	Average alkali rhyolite[3]
SiO_2	92.5	76.1	74.2
TiO_2	--	--	0.2
Al_2O_3	1.4	11.5	13.6
Fe_2O_3	0.5	2.4	2.2
MnO	--	0.2	--
MgO	0.1	0.1	0.3
CaO	3.0	1.6	1.1
Na_2O	0.1	2.0	3.0
K_2O	0.1	5.7	5.4

[1] Pettijohn (1957), p. 298
[2] ibid, p. 259
[3] Nockolds (1954), p. 1012

The value for the SiO_2 content of the average orthoquartzite given in Pettijohn (1957, p. 298) is unduly biased by the inclusion of a sample containing abundant calcite. The SiO_2 content of orthoquartzite without carbonate cement is about 97 to 99 per cent and that of protoquartzite (and sub-arkose) may be as much as about 95 per cent (op. cit.). It would seem, therefore, that sample 614-46-6 is the only one analysed which may be a meta-orthoquartzite. If the error in the analysis of this sample (total 101.7 per cent) is due entirely to an error in the determination of SiO_2 its true SiO_2 content would be only 95.5 per cent, which leaves it on the borderline between orthoquartzite and sub-arkose as defined by Pettijohn (1957, p. 322). On the other hand, perhaps the K_2O content is due mainly to K-metasomatism and hence should be subtracted in a chemical comparison, so that this sample would definitely fall in the orthoquartzite class. Modal analysis indicates that sample 614-46-6 is orthoquartzite rather than sub-arkose. It contains 91 per cent quartz, 5 per cent feldspar, and 4 per cent mica. The mica is probably in part or in whole derived from clay minerals and not from detrital feldspar grains. According to Pettijohn (1957, p. 322) sub-arkose is a rock whose detrital part consists of at least 10 per cent labile constituents of which feldspar forms half or more.

According to Gilbert's classification (Williams, Turner, and Gilbert, 1955, p. 316) sample 614-46-6 is a quartz arenite. This is defined as a rock containing less than 10 per cent argillaceous material and whose detrital content is 80 per cent or more quartz and chert.

Samples 614-38-5 (calcareous quartzite) and 614-22-19a (grey feldspathic quartzite) were derived from sub-arkose (Pettijohn's classification) or feldspathic arenite (Gilbert's classification). Sample 624-24-9 (pink feldspathic quartzite) is an arkosic rock as its CaO content precludes an igneous origin (see Table IX).

Its high Al_2O_3 and mica content (see Table XXXI) suggest derivation from a rock with a high clay mineral (kaolinite) content. If this is the case it was an arkosic wacke (Gilbert's classification) or feldspathic greywacke (Pettijohn's classification). The writer prefers the former term.

"Pelitic" class

Analysed samples belonging to the "pelitic" class are shown in Table X.

Table X: Chemical analysis of "pelitic" rocks belonging to the Meyers Lake Group and of standard rocks

	Sample Number and Classification				
	614-46-9 Biot.-musc.-qtz. schist	624-84-6 Biot.-musc.-qtz. schist	614-25-7 Biot.-musc.-qtz. schist	Average high grade pelite[1]	Average greywacke[2]
SiO_2	60.4	63.9	64.1	65.01	65.9
TiO_2	0.71	0.57	0.89	0.82	0.5
Al_2O_3	22.98	13.67	18.39	17.84	14.4
Fe_2O_3	5.46	7.75	4.11	7.38	5.7
MnO	0.04	0.05	0.02	--	0.1
MgO	2.9	3.8	6.0	2.38	3.0
CaO	0.20	0.63	0.43	1.27	3.6
Na_2O	0.65	1.10	0.45	2.0	3.5
K_2O	5.39	5.58	6.01	3.43	2.1
Total	98.8	97.1	101.2		

[1]Shaw (1956), p. 929
[2]Pettijohn (1949), p. 256

All three samples have Na_2O:K_2O weight per cent ratios of 0.20 or less, as compared to the ratio for the average high grade pelite of 0.59 (Shaw, 1956) and the ratio for the arithmetic mean of greywacke of 1.6 (Middleton, 1960). It appears that these samples are true pelites rather than greywacke.

As these rocks are associated with a quartzite sequence their maturity is of interest. Nanz (1953) suggested that maturity of lutites (pelites) can be estimated from the ratio Al_2O_3:Na_2O. He found that this ratio was 125 for an average of two

orthoquartzitic lutites. It was 11 for an average of two "greywackish" lutites. Ratios for samples 614-46-9, 614-84-6, and 614-25-7 are 35, 12, and 41 respectively. The average high and low grade pelites (from Shaw, 1956) have ratios of 9 and 10 respectively.

Depositional environment of the Meyers Lake Group

The Meyers Lake Group consists of a basal quartz-pebble meta-conglomerate, overlain by a sequence which was originally predominantly orthoquartzite and sub-arkose (Pettijohn's classification) or quartz arenite and feldspathic arenite (Gilbert's classification), with lesser amounts of intercalated pelites and very minor amounts of arkosic wacke (?) and quartz pebble conglomerate.

The Meyers Lake Group has little resemblance to any of the facies (consanguineous associations) characteristic of different depositional environments as outlined by Pettijohn (1957, p. 610). It does not belong to the greywacke suite, the subgreywacke suite, or the arkosic suite. It differs from the only other suite in this classification, the cratonic orthoquartzite-carbonate suite, in the absence of limestones and presence of abundant although subordinate pelites (perhaps 30 per cent) and of feldspathic sandstones (sub-arkoses). If the Meyers Lake Group is considered to be a variant of the orthoquartzite-carbonate suite, the lack of limestones could perhaps be attributed to the rarity of lime-secreting organisms when this sequence was deposited. This would result in carbonates being deposited chemically rather than organically and hence not being concentrated (although they would be precipitated) in shallow water environments in the way that they have been since the Cambrian. Nanz (1953, p. 59) found that Precambrian lutites (pelites) contain less CaO than younger lutites. He attributed this to the dominant role of inorganic precipitation and a resulting accumulation of lime in part on the deep sea floor during Precambrian times. With regard to the pelites, Pettijohn states (1957, p. 614) that,

[illegible] (Table 11) [illegible] average of two [illegible] [illegible]

[illegible]

Depositional environment of the [illegible] Lake Dome

The [illegible] Lake Dome [illegible] which was originally [illegible] orthoquartzite [illegible] arkose (Pettijohn's classification) [illegible] (Gilbert's classification), with minor amounts of [illegible] of arkosic wacke [illegible] pebble conglomerate.

The [illegible] Lake Dome [illegible] as outlined by Pettijohn (1957, p. 638). It does not belong to [illegible] the eugeosynclinal suite [illegible] in this classification [illegible] orthoquartzite [illegible] limestone and absence [illegible] [illegible] Lake Dome [illegible] would perhaps be attributed to the [illegible] sequences [illegible] [illegible] Precambrian [illegible]

[illegible]

> "The paucity of shale in the orthoquartzite-carbonate facies is not fully understood. If the carbonates are....wholly calcarenites, then the calcarenites and the normal quartzose arenites were the product of deposition in a turbulent environment. In such a case the finer silts or clays from the land would be by-passed into deeper less turbulent waters....many of the carbonates are in fact calcilutites or lime muds (so) it is difficult to believe that argillaceous materials were by-passed. It has been suggested that the clays were winnowed out in an earlier cycle and the sands associated with the carbonates are second-cycle and derived only from earlier sandstones."

This is of interest in light of the comments of Gilbert on feldspathic arenites and quartz arenites. He states (Williams, Turner, and Gilbert, 1955, p. 316) that,

> "By decrease in content of feldspar, feldspathic arenites grade into quartz arenites. In fact, some of the fine-grained laminae of strata of first-cycle quartz arenites may contain a considerable amount of feldspar, whereas coarser layers of the same rock contain none; and some quartz arenites that lie unconformably on old feldspathic rocks may contain moderate amounts of feldspar in their lower portions but decidedly less in their upper portions."

As the quartzites of the thesis area are completely re-crystallized it is impossible to tell if the more feldspathic rocks were originally of finer grain size. It was noted that the rare arkosic wackes or arkoses in the Meyers Lake Group do not occur higher than about 300 feet above the base of the quartzite, and there may well be a lower percentage of feldspathic arenites (sub-arkoses) towards the top of this unit as well. It seems quite possible that the Meyers Lake Group is a first-cycle sequence, which would explain the presence of both the pelites and feldspathic arenites or sub-arkoses.

Krumbein and Sloss (1956, p. 388-389) present an elaborate tectono-environmental classification of sedimentary rocks. In this classification there is no exact lithologic parallel to the Meyers Lake Group, but the closest resemblance is to the stable shelf occurrence, which is characterized by a lithologic assemblage very similar to Pettijohn's orthoquartzite-carbonate suite. The group does not resemble either the miogeosynclinal or eugeosynclinal group in the classification of Krumbein and Sloss.

The nature of the environment in which the Meyers Lake Group was formed

may also be considered on the basis of the preserved sedimentary features. The basal quartz-pebble meta-conglomerate has (1) a present lateral extent of at least 16 and possibly 36 miles; (2) recognizable cross-bedding in the least deformed outcrop; (3) a usual present thickness of 0 to 400 feet but a maximum present thickness of about 1300 feet, and (4) minor interlayers of pelites and quartzite. The orthoquartzitic (oligomictic) conglomerates are described by Pettijohn (1957, p. 256-257) as commonly being deposits of a transgressive beach over a surface of low relief, although similar conglomerates may be fluvial rather than marine. The lateral extent of the conglomerates of the Meyers Lake Group and the interlayered pelites within the conglomerates suggest that the marine environment is the more likely of the two possibilities. The interlayered pelites and quartzites probably represent times during which the beach zone was elsewhere and hence a fluctuating shoreline is visualized. It is noteworthy that not only were the conglomerates and quartzites laid down directly on the "older metamorphic rocks" but the pelites were also, suggesting that the rocks forming the base of the Meyers Lake Group represent both a beach facies and a deeper water facies. The only feature preserved in the quartzite which is of much value in determining its environment of formation is the presence of one recognizable example of cross-bedding or cross-lamination. According to Pettijohn (1957, p. 593) cross-bedding indicates deposition above the wave base. The pelites interlayered with the quartzites suggest marine deposition. There is a possibility, of course, that in part the quartzite is non-marine, either fluviatile or aeolian (beach dune sands), but the evidence of the meta-conglomerate, quartzite, and pelites does suggest predominantly shallow water, marine deposition.

This evidence for shallow water deposition, coupled with the maturity of the Meyers Lake Group and its thickness, suggests that the group was formed during a period of slow subsidence and that deposition very nearly kept pace with the subsidence. Although the group is not quite as mature as the typical cratonic orthoquartzite-carbonate suite of Pettijohn, it bears a much closer resemblance to this

suite than to the geosynclinal-type (?) "older metamorphic rocks" of the thesis area. It presumably was laid down during a long period of relative stability.

EPIDIORITE

Field relationships and textures indicate that the epidiorite is a metamorphosed plutonic rock. A comparison of an analysed sample and of average diorite is given in Table XI.

Table XI: Analyses and modified C.I.P.W. norms of epidiorite and of average diorite.

	Epidiorite (Sample 614-27-1)	Average diorite[1]
SiO_2	54.5	51.86
TiO_2	0.71	1.50
Al_2O_3	18.02	16.40
Fe_2O_3	6.82	10.40
MnO	0.09	0.18
MgO	7.6	6.12
CaO	8.32	8.40
Na_2O	3.65	3.36
K_2O	1.17	1.33
Total	100.9	
Q	0.2	0.3
or	6.9	7.8
ab	30.8	28.3
an	29.4	25.8
$CaSiO_3$	5.1	5.6
$MgSiO_3$	18.8	15.3
$FeSiO_3$	5.2	8.5
mt	3.9	3.9
il	1.3	2.9

[1] Nockolds (1954), p. 1019

As this table shows, the analysed sample of epidiorite is very similar to the average diorite, leaving no doubt that it is a metamorphosed diorite.

The metasomatized and migmatitic rocks

INTRODUCTION

The "metasomatized and migmatitic rocks" include the various rock types whose composition and/or textures suggest that either the addition or removal of considerable material has occurred during metamorphism or that the rock has undergone partial fusion. It is realized that certain of the "metamorphic" rocks discussed in the preceding section may have undergone metasomatism but, unlike the rocks discussed in this section, they show no evidence in the field of this.

ANTHOPHYLLITE-CORDIERITE-BIOTITE GNEISS

The anthophyllite in this rock type occurs in porphyroblasts which lie in random orientations across foliation planes (Plate XV, 1,2). This suggests that the anthophyllite is a late mineral and that perhaps the rock has been subjected to the influence of magnesium- and iron-bearing fluids after the cessation of the forces which led to the development of the foliation. An analysis of a typical sample (614-39-6, see Appendix XI) confirms that this rock type has undergone metasomatism. The MgO content, SiO_2 content, and MgO:CaO ratio of this sample preclude derivation from any sort of igneous rock, greywacke, or calcareous sedimentary rock without some metasomatism.

The anthophyllite-cordierite-biotite gneiss occurs only in association with the knobby biotite-plagioclase gneiss (map sub-unit 3a). Although these rock types were not seen in contact and hence their relationship is uncertain, derivation of the anthophyllite-cordierite-biotite gneiss from the knobby biotite-plagioclase gneiss (probably meta-greywacke) is a likely possibility. Cation percentages recalculated to 100 per cent for analysed samples of these rock types are compared

below:

	Knobby biot.-plag.gn. Sample 624-81-5	Antho.-cord.biot.gn. Sample 614-39-6
Si	58.6	58.7
Al	17.1	17.0
Na	8.0	3.2
Ca	1.6	0.9
K	3.6	1.8
Fe	3.5	4.5
Mn	0.1	0.1
Mg	7.2	14.1
Ti	0.4	0.4

The virtually identical percentages of Si and Al, probably the least mobile elements, indicates that the two rock types are probably closely related. The other percentages indicate that the anthophyllite-cordierite-biotite gneiss, if derived from the knobby biotite-plagioclase gneiss, has gained much Mg and minor Fe with the concurrent loss of Na, Ca, and K. This would correspond to a breakdown of some plagioclase and biotite, and formation of cordierite and anthophyllite. These are considered to be likely reactions.

MAP-UNIT (11): PORPHYROBLASTIC GNEISS, AUGEN GNEISS, MIGMATITE, AND GRANITIC GNEISS

It is suggested that potassium metasomatism or mobilization of granitic material has played a part in the formation of the rocks comprising this map unit. A rigorous proof of such metasomatism would require detailed mapping and sampling and numerous chemical analyses, and is beyond the scope of this study.

The porphyroblastic gneiss and augen gneiss are believed to be derived from most of the rock types which form map-units (1) to (10) inclusive. The development of porphyroblasts and augen in some of these rock types, for example the biotite schist and gneiss (map-unit (3)), does not necessarily indicate metasomatism, as they contained abundant potassium originally and the augen and porphyroblasts may be simply products of recrystallization. However, in other cases there is little doubt that the formation of potassium feldspar porphyroblasts implies metasomatism.

The best example is epidiorite, a fairly uniform rock which was originally potassium-poor, but which now contains up to 40 per cent potassium feldspar porphyroblasts locally. The development of biotite-rich potassium-feldspar porphyroblastic gneisses from hornblende-biotite rocks also implies metasomatism. It seems reasonable to suggest that the derivation of the augen-bearing rocks from the quartz-pebble meta-conglomerate and acidic meta-volcanic (?) rocks may involve potassium metasomatism, as in both cases there is a marked increase in percentage of feldspar porphyroblasts towards the contact of the units without any visible change in the nature of the matrix. This is not a facies change as the rocks in contact with these units belong to the augen gneiss-migmatite complex.

The mobilized granitic material of the migmatite and granite gneiss may be composed of the low melting point,quartzo-feldspathic components of the meta-morphic rocks themselves, or may be introduced material. The "stockwork" type of migmatite ("agmatite", see Plate XVI), as developed in amphibolite, epidiorite, and hypersthene amphibolite, indicates that the granitic material was introduced. Migmatites in which the quartzo-feldspathic component occurs as discontinuous streaks or persistent thin parallel layers suggest a local "sweating out" of the quartzo-feldspathic component of the rock itself. It is probably that both processes have operated within the thesis area and perhaps commonly within the same rock.

The intrusive rocks

INTRODUCTION

The intrusive rocks include four map-units, the western granitic rocks (12), the eastern granitic rocks (13), pegmatite (14), and vein quartz (15). The rocks comprising all four map-units show intrusive relationships in some places to other rock-types, but some may be derived from re-mobilized metamorphic rocks, some may be magmatic differentiates, and some in part may have formed through meta-

somatism of pre-existing rocks. The following sections discuss these possibilities.

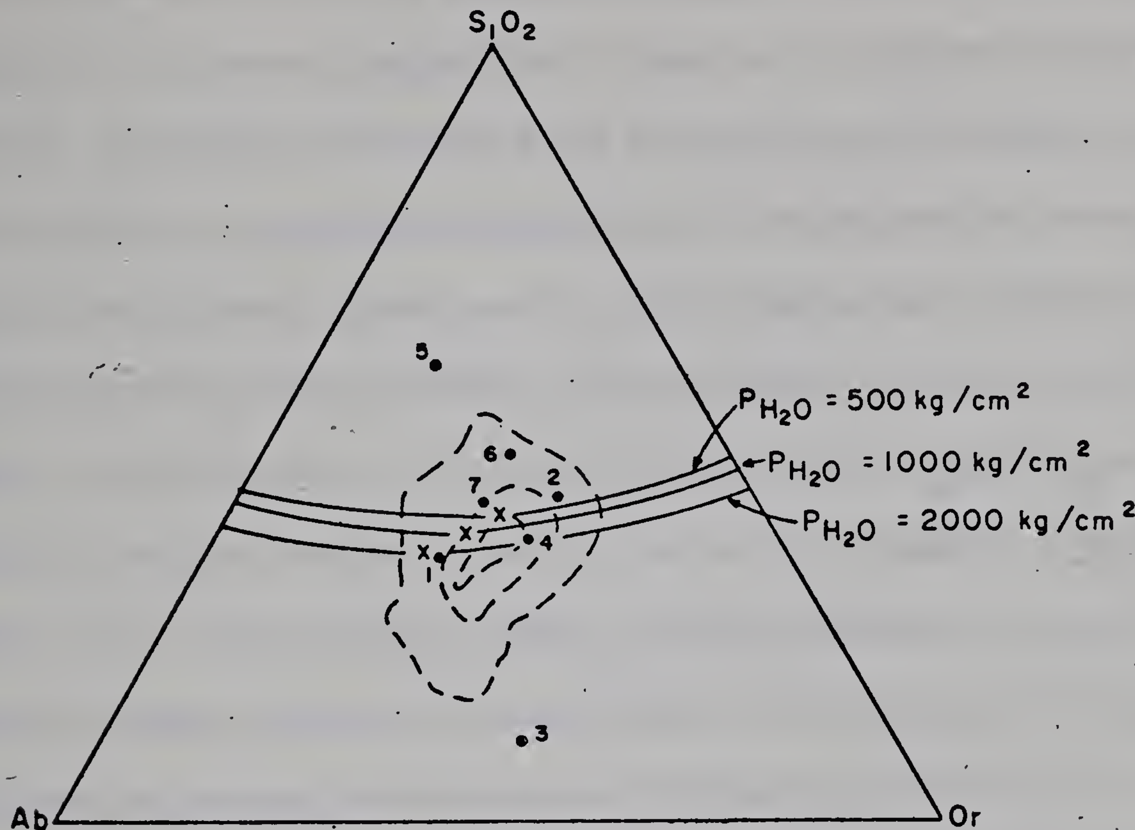
UNIT (12): WESTERN GRANITIC ROCKS

The western granitic rocks are known to be intrusive into metamorphic rocks which are part of the "older metamorphic rocks" and the "cordierite-garnet rocks" (see Chapter II). Within the main bodies of the western granitic rocks a number of inclusions were noted. Some of these have very diffuse boundaries and, rarely, porphyroblastic pink potassium feldspar, indicating either local granitization of the inclusions or partial assimilation into a melt accompanied by metasomatic (?) development of feldspars in the unassimilated part. Other inclusions have sharp, distinct boundaries. A few of these inclusions are rotated, indicating that the surrounding granitic rocks were mobile. The western granitic rocks are probably pre-Hudsonian in age and older (in time of initial crystallization) than at least some of the rocks ("older metamorphic rocks, "cordierite-garnet rocks") that they intrude (see Chapter VI). Therefore, the above evidence indicates only that they have undergone some remobilization during the Hudsonian orogeny and provides no evidence as to their origin.

Analysed samples of the western granitic rocks (see Appendix XI) all have normative ab+or+Q greater than 80 and hence have been compared with the contour diagram for all such rocks (Tuttle and Bowen, 1958, p. 79) and with the isobaric minimum at different water pressures (ibid., p. 75) on Figure 5. The two samples of typical rocks (614-28-6; 624-53-5) fall near the isobaric minimum at water-vapour pressures of about 2000 kg/cm^2 and 200 kg/cm^2 respectively. A sample of monzonite (Figure 5, no. 3), however, occurs well outside of the one per cent contour of the contour diagram and does not appear to be related to the isobaric minimum. Its position on Figure 5 suggests that despite a differentiation index (normative or+ab+Q) of 89 (normative minerals recalculated to 100 per cent) it is not a normal member of Bowen's "petrogeny's residua system" (Tuttle and

FIGURE 5

PLOT OF NORMATIVE QUARTZ, ALBITE, AND ORTHOCLASE FOR ANALYSED SAMPLES OF THE GRANITIC ROCKS AND PEGMATITES OF THE NEEDLE FALLS AREA WHICH HAVE (Q+ab+or) EQUAL TO OR GREATER THAN 80



Contour diagram of normative albite, orthoclase and quartz in 571 rocks in which (ab + or + Q) is equal to or greater than 80. (after Tuttle and Bowen, 1958, p 79)

——— Boundary between the quartz and feldspar fields at various water-vapor pressures (after Tuttle and Bowen, 1958, p 75)

x Isobaric minimum

SAMPLES, NEEDLE FALLS AREA

1. #614-28-6, map unit 12
2. #624-53-5, map unit 12
3. #624-97-3b, map unit 12
4. #614-31-8, map unit 13
5. #614-41-6b, map unit 14
6. #614-S-2, map unit 14
7. #644-Y2-6, map unit 14

Bowen, 1958, p. 128). As this map-unit is pre-Hudsonian in age (see Chapter VI) its composition may have been changed during the Hudsonian orogeny. There are three processes which could change the composition of this sample from "normal granitic" to its present composition. These are (1) metasomatic addition of Na, K, and Al; (2) addition of Na and K and loss of Ca; and (3) selective loss of Si. The first possibility is considered improbable, as Al-metasomatism is most unlikely. The second would involve breakdown of a calcic plagioclase and formation of sodic plagioclase and potassium feldspar. This is possible, but there is much more variability in the Q/F ratio (0.10 to 0.67) than the K_2O+Na_2O/CaO ratio (0.67 to 0.78) in analysed samples of this unit, so the third possibility is considered the most likely one. Tuttle and Bowen (1958, p. 90-91) reported on the results of experiments in vapour-hydrous granite equilibria. If the vapour was allowed to escape the principal change in composition in the hydrous granite was a loss of silica. Tuttle and Bowen suggested (1958, p. 90) that the compositional changes are due to diffusion through the vapour rather than actual movement of the vapour itself. This process offers a possible mechanism for the formation not only of rocks such as sample 624-97-3b, but perhaps also for the giant quartz veins of the thesis area.

It is suggested, on the basis of the preceding discussion, that the western granitic rocks: (1) probably originally crystallized from a magma (typical samples plot near the isobaric minimum); (2) may have undergone a considerable selective loss of SiO_2 locally during the Hudsonian orogeny; and (3) were re-mobilized in part during the Hudsonian orogeny.

UNIT (13): EASTERN GRANITIC ROCKS

The eastern granitic rocks are fringed on the west by a porphyroblastic potassium feldspar gneiss-augen gneiss-migmatite complex as much as five miles in width which is probably at least in part related to them. The rocks of this complex grade into the eastern granitic rocks as the proportion of granitic rocks within

the migmatite increases. The "contacts" shown on the maps (Figures 16 and 17) are arbitrary. The potassium feldspar porphyroblasts that are characteristic of the complex are very similar in appearance to those in the marginal phases of the eastern granitic rocks. Away from this marginal zone, in the main body of the eastern granitic rocks, migmatites are scarce, some inclusions have sharp, distinct boundaries and are rotated (Plate XX, 1) and the granitic component of migmatites in general seems to be intrusive, so that the eastern granitic rocks are probably intrusive in nature. If so, the porphyroblastic potassium feldspar gneiss-augen gneiss-migmatite complex is probably a contact metasomatized zone related to solutions and vapours derived from the eastern granitic rocks during their crystallization.

Only one of the three analysed samples of this map-unit (614-31-8) has a sufficiently high differentiation index (normative Q+or+ab = 89) to plot on Figure 5. Its position on this figure suggests that it is a product of a magma rather than being due to metasomatism, and that it was formed at a water-vapour pressure of slightly less than 2000 kg/cm^2. (Tuttle and Bowen, 1958, p. 75,77). The temperature of crystallization was above 700°C and less than 740°C (Tuttle and Bowen, 1958, p. 55). The inferred water-vapour pressure and temperature are accurate only if the analysis is accurate. Sample 614-31-8 gives an anhydrous total weight per cent of 100.2 and has 1.4 per cent normative C. It contains only 4 per cent hydrous minerals (mica) so the analysis is regarded as good. However, it contains 7.8 per cent normative an, which presumably indicates crystallization at slightly higher temperatures and perhaps slightly different pressures than Figure 5 indicates. This sample is a more highly differentiated rock than the bulk of the rock types forming this unit (the differentiation indices of samples 614-85-1 and 634-88-3 are 68 and 69 respectively) and hence probably indicates the temperature of final or nearly final crystallization.

UNIT (14): PEGMATITE

The pegmatite bodies within the thesis area are probably not all of the same origin and may not all be of the same age. Certain pegmatites are probably segregation pegmatites, as indicated by a mineralogy similar to that of the host rock, their generally concordant nature, and lack of mineral zoning or chilled margins. In this category can be included the muscovite pegmatite lenses in the meta-arkose (unit 1), the cordierite-garnet-sillimanite pegmatites in the cordieritic rocks (unit 5), and probably some of the common potassium feldspar-plagioclase-quartz-biotite pegmatite. Pegmatites of probable or possible igneous affinities include the porphyritic and tourmaline-bearing pegmatites found near Sandfly Lake and occasional small pegmatite bodies of the common quartz-feldspar-biotite type which occur within granitic rocks. In addition, the large, seemingly concordant pegmatite lens on the north shore of MacDougall Bay is, simply on the basis of its size, probably magmatic. Smaller but similar concordant bodies elsewhere may also be magmatic.

Three samples of pegmatite have been analysed and are plotted on Figure 5. Two samples (614-41-6b; 614-S2) plot much closer to the SiO_2 corner than the isobaric minimum; the third (644-Y2-6) approximately coincides with the (extrapolated) isobaric section at the water-vapour pressure of nearly 0 kg/cm^2. If the analyses can be relied on this suggests that two or perhaps all three samples have been enriched in SiO_2. However, the analyses of pegmatite samples 614-41-6b and 614-S2 are poor so the plots of both may be inaccurate.

Two of the three analysed samples do not closely resemble either of the major granitic bodies chemically. The third sample (614-41-6b) has a very high Sr content and extremely low Rb:Sr ratio, a feature which it shares with the eastern granitic rocks. It is probably genetically related to them.

UNIT (15): VEIN QUARTZ

The contact relationships of the vein quartz (discussed in Chapter III) and the presence of inclusions of metamorphic rocks within the quartz veins indicate that the vein quartz is truly intrusive and is not metamorphosed quartzite. There are three possible origins for this rock type. It may be either a magmatic or metamorphic differentiation product of the granitic rocks, or it may be mobilized and recrystallized quartzite.

The possibility of development of the quartz veins from SiO_2-rich vapours derived from the western granitic rocks has been alluded to in the section on the western granitic rocks. The quartz veins have a greater exposed area than that of the known extent of their possible parents (monzonite, map sub-unit 12a), but more monzonite may occur north of the Sandfly Lake Area (East Half). There is considerable uncertainty concerning the composition of such vapours (Tuttle and Bowen, 1958, p. 91) but they may contain too much orthoclase to form a rock with the composition of the vein quartz.

Comparison of the vein quartz and quartzite (Table XII) does not offer much evidence for or against derivation of the vein quartz from the quartzite.

Table XII: Chemical compositions of vein quartz (unit 15) and quartzite (unit 8).

	Sample 624-59-17 (Vein quartz)	Sample 614-46-6 (Quartzite, unit 8)
SiO_2	99.2	97.2
TiO_2	0.04	0.03
Al_2O_3	1.43	2.53
Fe_2O_3	0.49	0.59
MnO	0.01	0.01
MgO	--	-
CaO	0.02	0.07
Na_2O	0.04	0.07
K_2O	0.22	0.18
Total	101.5	101.7
Sr (ppm)	--	14
Rb (ppm)	--	28

Frarey (1950, p.7) reported that a similar but smaller occurrence of vein quartz, about 27 miles west-northwest of the northwest corner of the Sandfly Lake Area (East Half), can be seen in contact with quartzite, which is much finer in texture and more foliated. This could be evidence for a different origin for the two rock types, but the "quartzite" of Frarey could be a more sheared variant of the vein quartz.

It is concluded that the origin of the vein quartz is uncertain. Sillimanite is present in the vein quartz and it is abundant in inclusions, indicating a minimum temperature of formation of 300°C (Bell, 1963) for at least part of the vein quartz. Alternatively, a later metamorphism of the vein and inclusions may have produced the sillimanite.

Chapter V

CONDITIONS OF METAMORPHISM

Mineral Assemblages and Metamorphic Facies

The origin of the concept of metamorphic facies and early classifications have been fully discussed by Fyfe, Turner, and Verhoogen (1958, especially p. 3-13). The metamorphic assemblages of the thesis area will be considered in the following section on the basis of their widely used classification, some anomalies will be pointed out, and the assemblages will then be discussed in terms of Miyashiro's (1961) classification.

Mineral assemblages that may be used to determine the metamorphic grade of the rocks of the map-area are listed in Table XIII. In compiling this table, accessory minerals and minor amounts of alteration products have been disregarded. The numbered assemblages are those considered by Turner (Fyfe, Turner and Verhoogen, 1958) to be in equilibrium. Lettered assemblages are those that he considers to be in disequilibrium but which are of interest in the determination of metamorphic grade.

Table XIII. Mineral assemblages in the metamorphic rocks

Assemblage Number or Letter	Minerals Present
I	Biotite-garnet-microcline-plagioclase[1]-sillimanite-quartz (5)[2]
II	Biotite-garnet-microcline-plagioclase-quartz (5)
A	Biotite-cordierite-garnet-microcline-plagioclase-sillimanite-quartz (5)
B	Biotite-cordierite-microcline-plagioclase-sillimanite-quartz (5)
III	Hornblende-hypersthene-plagioclase-quartz (6a)
C	Hornblende-hypersthene-biotite-plagioclase-quartz (6a)
IV	Clinopyroxene-hornblende (6b)
V	Muscovite-microcline-plagioclase-quartz (1,2,7,8,9)
VI	Muscovite-biotite-microcline-plagioclase-quartz (1,2,7,8,9,11)

[1] The plagioclase is more calcic than albite in all rocks.
[2] The number(s) in brackets indicate the map unit(s) in which the assemblage is found.

Table XIII. continued

Assemblage Number or Letter	Minerals Present
D	Muscovite-sillimanite-microcline-plagioclase-quartz (1)
E	Muscovite-biotite-garnet-microcline-plagioclase-quartz (1)
VII	Hornblende-biotite-microcline-plagioclase-epidote-quartz (1,2,3,4,12)
VIII	Hornblende-biotite-plagioclase-epidote-quartz (1,2,3,4)
IX	Hornblende-biotite-plagioclase-quartz (1,2,3,4)
X	Hornblende-biotite-clinopyroxene-plagioclase-quartz (2,5)
XI	Hornblende-biotite-microcline-plagioclase-quartz (2,3,10,11,12)
XII	Biotite-plagioclase-quartz (2, 3a)
XIII	Biotite-microcline -plagioclase-quartz (2,3,4,11,12)
XIV	Biotite-muscovite-plagioclase-quartz (3b,7,8,9)
XV	Biotite-microcline-plagioclase-epidote-quartz (4)
XVI	Biotite-muscovite-microcline-quartz (7,8,9)
XVII	Biotite-muscovite-andalusite-quartz (8,9)
F	Biotite-diopside-actinolite-microcline-plagioclase-epidote-carbonate-quartz (8)
G	Biotite-actinolite-microcline-plagioclase-epidote-quartz (7,8,9)
H	Actinolite-microcline-plagioclase-epidote-carbonate-quartz (8)
J[3]	Actinolite-muscovite-microcline-plagioclase-quartz (7,8,9)
K	Actinolite-microcline-plagioclase-quartz (7,8,9)
L	Biotite-muscovite-andalusite-sillimanite-quartz (8, 9)
M	Cordierite-anthophyllite-biotite-chlorite-plagioclase-quartz (3a)

[3]The letter I is omitted to prevent confusion with the Roman numeral I.

According to Turner's classification (Fyfe, Turner, and Verhoogen, 1958, p. 205-235), the equilibrium assemblages belong in part to the hornblende hornfels facies, in part to the almandine amphibolite facies, and in part to the granulite facies. This is tabulated below:

Table XIV. The metamorphic rocks of the thesis area in terms of Turner's (1958) facies classification

Facies and Subfacies	Assemblage Numbers
Hornblende hornfels facies	XVII
Hornblende hornfels facies or almandine amphibolite facies, staurolite-quartz or kyanite-muscovite-quartz subfacies	V, VI, XII, XIII, XIV, XVI
Hornblende hornfels facies or almandine amphibolite facies, sillimanite-almandine subfacies	VII, VIII, IX, XI
Hornblende hornfels facies or almandine amphibolite facies	X
Almandine amphibolite facies, staurolite-quartz or kyanite-muscovite quartz subfacies	XV
Almandine amphibolite facies, sillimanite-almandine subfacies	I, II
Granulite facies, hornblende granulite subfacies	III

(Because of its limited mineralogy, Assemblage IV is not characteritistic of any given facies)

Assemblages A and B are confined to unit (5). They are probably equilibrium assemblages although not so considered by Turner. Barker (1962, p. 907), in a paper on similar assemblages states that:

> "Gneiss of argillaceous composition....consists of the assemblage biotite-cordierite-garnet-magnetite-microcline-quartz-plagioclase-sillimanite. The conclusion is made that this assemblage does not violate the phase rule."

Wynne-Edwards and Hay (1963, p. 457-458) list 10 references from the literature on regional occurrences of garnet-cordierite-sillimanite-biotite gneisses. They conclude (ibid, p. 471) that garnet-sillimanite-cordierite-potassium feldspar-quartz-biotite (assemblage A) is a stable regional metamorphic assemblage in rocks of appropriate composition. Assemblages A and B have some resemblance to

the assemblage quartz-oligoclase-cordierite-sillimanite-biotite-muscovite which Turner (Fyfe, Turner, and Verhoogen, 1958, p. 211) considers to be in equilibrium and to represent a transition between the almandine amphibolite facies and the high temperature field of the hornblende hornfels facies.

Assemblage C (hornblende-hypersthene-biotite-plagioclase-quartz) is confined to sub-unit (6a). It probably represents retrograde metamorphism of assemblage III (hornblende-hypersthene-plagioclase-quartz), which belongs to the granulite facies, hornblende granulite subfacies and occurs only in the same sub-unit. Assemblages D (muscovite-sillimanite-microcline-plagioclase-quartz) and E (muscovite-biotite-garnet-microcline-plagioclase-quartz) both are found in meta-arkose (unit 1) within the eastern fold belt. Both are probably transitional from the hornblende hornfels facies or almandine amphibolite facies, staurolite-quartz subfacies, to the almandine amphibolite facies, sillimanite-almandine subfacies.

The calcareous assemblages F to K inclusive, all occurring only in the calcareous quartzite belonging to the Meyers Lake Group, present a problem. The presence in them of a calcic plagioclase indicates a metamorphic grade at least as high as the hornblende hornfels facies or the almandine amphibolite facies. However, it is generally considered that rocks of the lowest grades within these facies should contain diopside in place of or accompanying tremolite-actinolite. This is so only in assemblage F, which was seen only in one thin section. Bowen (1940) has discussed the progressive metamorphism of siliceous limestone and dolomite and suggests that the following reactions may take place with increasing temperature:

1. Dolomite + Quartz $\longrightarrow$ Tremolite + Calcite + CO_2
2. Tremolite + Dolomite $\longrightarrow$ Calcite + Forsterite + CO_2
3. Tremolite + Calcite + Quartz $\longrightarrow$ Diopside + CO_2

4. Calcite + Tremolite $\longrightarrow$ Diopside + Forsterite + CO_2

Bowen points out (1940, p. 245) that these reactions involve progressive decarbonation, and that when starting mixtures are completely converted to silicates no further reactions will take place. The calcareous quartzites of the thesis area are sufficiently siliceous that all their dolomite should be used in reaction 1 and reaction 2 would not occur. At higher temperatures reaction 3 should use all the calcite and reaction 4 would not occur. The three stable assemblages for these rocks, in order of increasing grade of metamorphism, and ignoring CO_2 are, therefore, (1) dolomite + quartz, (2) tremolite + calcite + quartz, and (3) diopside + tremolite + quartz. Assemblages actually occurring in the calcareous quartzites are complicated by the presence of additional minerals, including biotite, microcline, plagioclase and epidote. Temporarily ignoring these, the natural assemblages are: F, diopside-actinolite-carbonate-quartz; G, J, K, actinolite-quartz; H, actinolite-carbonate-quartz. If we consider only the minerals diopside, actinolite, calcite and quartz, assemblage F is a disequilibrium assemblage (Bowen, 1940, p. 244, figs. 2, 3). Assemblage H is an equilibrium assemblage indicating that reaction 1 has occurred but not reaction 3. Assemblages G, J and K also indicate equilibrium, and may also indicate that the rocks have undergone reaction 1 but not reaction 3. If the calcite produced in reaction 1 is used in some other reaction, for example in forming plagioclase or epidote, then the assemblage actinolite + quartz would be stable to the breakdown temperature of actinolite. The breakdown temperature for tremolite is about 820°C at a pressure of one kilobar (Boyd, 1959, p. 383). For actinolite it should be even higher, so actinolite would be stable in the upper part of the amphibolite facies and hence assemblages G, J, and K could belong to the upper part of this facies. Assemblage H occurs in only one thin section, and is probably not typical of the calcareous quartzites as a whole. Its complete assemblage

is actinolite-microcline-plagioclase (andesine)-epidote-carbonate-quartz. Goldschmidt's mineralogical phase rule may be applied to determine whether this assemblage can be in equilibrium. The equation for this is P = C

where P = number of phases at equilibrium
C = number of components

There are 6 phases (minerals) in this rock, and a maximum of 8 independent components (SiO_2, Al_2O_3, K_2O, CaO, Na_2O, FeO, Fe_2O_3, MgO), ignoring H_2O, CO_2, and minor elements. It seems that this assemblage could be in equilibrium, even if Fe_2O_3, FeO and MgO were not independent components. It is difficult to see where it fits into the facies classification, but the writer would tentatively put it in the amphibolite facies of Miyashiro (1961) on the basis of its calcic plagioclase (andesine).

Assemblage L (biotite-muscovite-andalusite-sillimanite-quartz) is confined to the biotite-muscovite-quartz schist which forms part of the Meyers Lake Group. In terms of Turner's classification it probably indicates conversion of hornblende hornfels rocks (assemblage XVIII) to the almandine amphibolite facies, sillimanite-almandine subfacies, as the sillimanite in these rocks replaces the andalusite.

Assemblage M (cordierite-anthophyllite-biotite-chlorite-plagioclase-quartz), found only in the cordierite-anthophyllite-biotite gneiss, is in disequilibrium. The mode of occurrence of the anthophyllite shows that it probably did not form during the main period of metamorphism. The cordierite may have done so, however, and, if so, is indicative of contact metamorphism rather than regional metamorphism in terms of Turner's classification.

Possible explanations for the supposed presence of rocks of several metamorphic facies in a given area are: (1) progressive contact or regional metamorphism; (2) polymetamorphism; (3) that the classification of metamorphic facies in use is in error or is incomplete; and (4) any combination of the preceeding explanations. On the basis of Turner's classification, this area was not

affected by progressive contact or regional metamorphism only, as it contains assemblages belonging to the hornblende hornfels facies, a facies of contact metamorphism, and the almandine amphibolite and granulite facies, which are facies of regional metamorphism. Turner states (Fyfe, Turner and Verhoogen, 1958, p. 201):

> "The classic distinction between contact and regional metamorphism expresses a real two-fold division of the metamorphic environment. Contact metamorphism is most clearly exemplified where aureoles have developed in otherwise almost unaltered rocks adjacent to plutonic intrusions. Field evidence alone indicates that contact metamorphism, as described in petrological literature, occurs at depths notably smaller than those of regional metamorphism."

Miyashiro (1961) has suggested that this view is untenable. He suggests that, instead of there being one group of facies of regional metamorphism whose boundaries are determined mainly by temperature, there are several groups of facies, each of which he refers to as a "facies series". The facies of each series are differentiated from the facies of each other series by being formed at different rock pressures. The five facies series that he proposes, listed in order of increasing rock pressure, are: (1) andalusite-sillimanite type; (2) low-pressure intermediate group; (3) kyanite-sillimanite type; (4) high-pressure intermediate group; and (5) jadeite-glaucophane type. The andalusite-sillimanite type comprises regionally metamorphosed rocks which were metamorphosed at pressure so low that their mineral assemblages closely resemble those of Turner's hornblende hornfels facies of contact metamorphism. The facies series of the kyanite-sillimanite type is the series widely regarded as being normal and is essentially the basis for Turner's classification of regionally metamorphosed rocks. It is sometimes called the Dalradian or Barrovian type of metamorphism. Miyashiro states (1961, p. 279) that:

> "If all the world is considered, this type may not be more abundant than the other two standard types (of regional metamorphism). It is not justified to regard this type as being 'normal' or ordinary in comparison with the other two, as was done by many authors."

The characteristics of the kyanite-sillimanite type are shown in Table XV, from Miyashiro (1961, p. 279).

Table XV: Mineralogy of the kyanite sillimanite type of facies series

Metamorphic facies		Greenschist facies	Epidote-amphibolite facies	Amphibolite facies	
Mineral zoning		Chlorite and biotite zones	Almandine zone	Staurolite and kyanite zones	Sillimanite zone
Basic Rocks	Sodic plagioclase	———	———		
	Intermediate and calcic plagioclase		——	———	———
	Epidote	———	———	——	
	Amphibole	Actinolite	Blue-green hornblende	Green (?) hornblende	Green and brown hornblendes
	Chlorite	———	——		
	Almandine		———	———	———
Pelitic Rocks	Chlorite	———	——		
	Muscovite	———	———	———	——
	Biotite	——	———	———	———
	Almandine		———	———	———
	Staurolite			——	
	Kyanite			—	
	Sillimanite				——
	Sodic plagioclase	———	———	———	———
	Quartz	———	———	———	———
Common pelitic rocks		Phyllite and schist	Schist	Gneiss	

(Table based on progressive mineralogical variations in regional metamorphism in the main part of the Grampian Highlands of Scotland).

The andalusite-sillimanite type of facies series, is characterized by the stability of andalusite in a lower grade and sillimanite in a higher grade, is shown in the following table, also from Miyashiro (1961, p. 280).

Table XVI: Mineralogy of the andalusite-sillimanite type of facies series

Metamorphic facies		Greenschist facies	Amphibolite facies		Granulite facies
Mineral zoning		A	B	C	D
Basic Rocks	Sodic plagioclase				
	Intermediate and calcic plagioclase				
	Epidote				
	Calciferous amphibole	Actinolite	Blue-green hornblende	Green and brown horn-blendes	Brown hornblende
	Cummingtonite				
	Chlorite				
	Calcite				
	Clinopyroxene				
	Orthopyroxene				
Pelitic Rocks	Chlorite				
	Muscovite				
	Biotite				
	Pyralspite	MnO > 18%	MnO-18 to 10%	MnO<10%	
	Andalusite				
	Sillimanite				
	Cordierite				
	Plagioclase				

Table XVI. continued

K-feldspar				
Quartz				
Common rocks	Phyllite and Schist	Schist	Amphibolite and gneiss	Amphibolite

(Table based on progressive mineralogical variations in regional metamorphism in the central Abukuma Plateau, Japan.)

According to Miyashiro (1961, p. 281, p. 303-304) this type of regional metamorphism is present in the Abukuma-Ryoke metamorphic belt of Japan, some Early Paleozoic metamorphic belts in New South Wales, Australia, and the Sveco-fennides of the Baltic Shield. In the Grenville province, the Superior province, and in the vicinity of Great Slave Lake in the Canadian Shield, assemblages belonging to the low-pressure intermediate type occur. These are characterized by minerals indicative both of the kyanite-sillimanite type and of the andalusite-sillimanite type of regional metamorphism, in close association.

In the thesis area the supposed contact metamorphic assemblage (XVII, biotite-muscovite-andalusite-quartz) is found in a tightly folded and contorted schist. The characteristic "contact metamorphic" mineral within it is andalusite. The andalusite grains are elongate parallel to the foliation; one was seen which curves around the axis of a crenulation, and another appears to be rotated and has an adjacent quartz-rich area which could be a pressure shadow effect (Plate XII). These textures suggest that the supposed contact metamorphic assemblage biotite-muscovite-andalusite-quartz may actually have developed under conditions of regional, dynamothermal metamorphism. The andalusite-bearing assemblage is particularly common in biotite-muscovite-quartz schist and gneiss (unit 9) immediately east of Acorn and Brunning Lakes, Eulas Lake Area (West Half), in the centre of the eastern fold belt in an

area where intrusive rocks are lacking. This also suggests that this assemblage is not due to contact metamorphism.

This evidence, and the regional extent of the cordierite-bearing assemblages (known strike length about 400 miles) indicates that the metamorphic rocks in the map-area have undergone regional metamorphism of the andalusite-sillimanite type (See Table XVI). In determining the metamorphic facies which are present, the assemblages which are most useful are the pelitic assemblages I, II, XVII, A, B, D, and L; and the basic assemblages III, VII, VIII, IX, X and XI, as these are the only types of assemblages for which Miyashiro gives mineral zoning (Table XVI). The garnet- and/or cordierite-bearing pelitic rocks outside of the eastern fold belt (I, II, A, and B) belong to the amphibolite facies, mineral zone C, possibly except II which could belong to zone B. The andalusite-bearing equilibrium assemblage (XVII) within the eastern fold belt belongs to the amphibolite facies, mineral zone B, while the disequilibrium assemblage L indicates incomplete progressive metamorphism from mineral zone B to zone C. Assemblage D probably also indicates mineral zone C. The hypersthene-bearing basic assemblage III belongs to the granulite facies and all the other basic assemblages to the amphibolite facies. An examination of twenty-five thin sections of hornblende-biotite rocks and amphibolites containing these assemblages was made to determine, on the basis of hornblende colour, whether they belonged to mineral zone B or C. Of these, thirteen contained blue-green hornblende (mineral zone B) and twelve contained green or brown hornblende (mineral zone C). Ten of the former and four of the latter are from the eastern fold belt while the remainder are from outside of this belt. All of the other assemblages considered stable by Turner, except XV, could belong to his hornblende hornfels facies on the basis of mineralogy, and hence could belong to the amphibolite facies, andalusite-sillimanite type, of Miyashiro. The presence of epidote in assemblage XV indicates that it does not belong to the hornblende hornfels facies of Turner, but its status with

regard to Miyashiro's classification is uncertain. This assemblage could possibly indicate that the metamorphic rocks of the thesis area belong at least in part to the low pressure intermediate type of regional metamorphism. Assemblages F to K, the actinolite-calcic plagioclase rocks, as previously suggested, probably could belong to the amphibolite facies.

With the sole exception of assemblage III (hypersthene-bearing), all stable assemblages belong to the amphibolite facies. The andalusite-bearing stable assemblage (XVII), which is confined to the Meyers Lake Group, indicates that in part that group belongs to mineral zone B (Table XVI). Hornblende colour suggests that rocks of mineral zone B may be predominant in the eastern fold belt, in which the Meyers Lake Group occurs. However, in part the eastern fold belt probably belongs to mineral zone C. The pelitic rocks which occur outside of this fold belt mainly or wholly belong to mineral zone C and hornblende colour suggests that most but not all of the amphibolites occurrring outside of the eastern fold belt also belong to this mineral zone. The exceptions appear to belong to mineral zone B. The granulite facies assemblage is confined to inclusions in granitic rocks and does not represent normal conditions for the area.

Pressure-Temperature Conditions

PROBLEMS IN APPLYING EXPERIMENTAL DATA TO NATURAL ASSEMBLAGES

This section attempts to relate the mineral assemblages of the metamorphic rocks in the area to experimentally determined stability fields for their constituent minerals. Fyfe, Turner, and Verhoogen stated (1958, p. 179-180) that:

> "At the present time correlation between available meagre experimental data and the accumulated geological evidence regarding metamorphic facies is as good as can be expected... The fundamental problem of the experimentalist and petrologist alike concerns the range of physical conditions to be assigned to each of the associations which have been recognized as individual facies or subfacies.
>
> Petrologists have long recognized that problems of metamorphism are concerned with stability fields of mineral assemblages, not single minerals.

> Experimentalists have tended to concentrate on stability fields of single phases whose conditions of formation may be profoundly modified in the complex natural assemblages. Such laboratory work will be useful in leading to ultimate synthesis of a naturally occurring assemblage; but it cannot be applied unreservedly and directly to problems of metamorphic facies. The work of Kracek, Neuvonen and Burley on jadeite, of Yoder on talc, and the present writers work on silica-rich versus silica-deficient environment, show that stability fields can be changed by 100°C or more and several thousand bars by presence of some associated phase."

This statement is pertinent today, even though the experimental evidence has become somewhat less meager. Nevertheless, the experimental data can be used if treated with due caution. This is best discussed by considering some examples.

The first is the work of Clark (1961) on the equilibrium relations between kyanite and sillimanite. Clark (1961, p. 642-643) synthesized these polymorphs of Al_2SiO_5. He found that the boundary was reversible (to within a kilobar) by forming sillimanite from kyanite and kyanite from sillimanite at appropriate temperatures and pressures (Figure 6, curve 1). This demonstrates that the boundary curve is an equilibrium curve. As natural sillimanite and kyanite are very close to Al_2SiO_5 in composition, their equilibrium relations should be little affected by complicating factors such as the bulk composition of the rock in which they occur or partial pressures of volatile components. Clark's kyanite-sillimanite curve is, therefore, valuable because it is an equilibrium curve for substances of nearly fixed composition. This curve, however, loses some of its usefulness because it was established only for the range of 900°C to 1500°C and about 15 to 24 kilobars, outside of the field of normal metamorphic environments.

The second example is the work of Khitarov, Pugin, Chao, and Slutskii (1963) on the stability of andalusite, kyanite, sillimanite and mullite. They were able to synthesize these minerals, draw boundary curves (Figure 6, curves 2A, 2B, 2C, 2D) and establish the kyanite-sillimanite-andalusite triple point and the sillimanite-andalusite-mullite (plus quartz) triple point at much lower temperatures and pressures than Clark. Their kyanite-sillimanite curve intersects Clark's extrapolated curve

within the experimental error. However, Khitarov _et al_. (_op. cit_), made no attempt to determine whether or not the minerals they synthesized formed stably or metastably, and their boundary curves may represent fields of metastable crystallization of the Al_2SiO_5 polymorphs and mullite. Khitarov _et al_., (1963, p. 240-241) state,

> "Although the experimental points in the region below 9000 atm do not necessarily represent stable conditions, still the andalusite-sillimanite boundary drawn through these points must very nearly coincide with the equilibrium curve."

Their viewpoint is open to question. Weill and Fyfe (1961, p. 1194) conclude from solubility and entropy data that andalusite

> "has no true stability field with respect to sillimanite at metamorphic temperatures and pressures."

They emphasize that their treatment is valid _only_ for the phases which do not deviate appreciably from the ideal composition Al_2SiO_5. Khitarov _et al_. do not give any analyses of their starting material, so that the andalusite formed in their experiment may have been stabilized by the presence of a minor amount of some other component or may have formed metastably. Another possibility is that Weill and Fyfe's work is not valid. The very widespread occurrence of andalusite in metamorphosed rocks suggests that andalusite does have some field of stability under natural conditions. Since the above discussion was written the writer became aware of Bell's (1963) work in which he determined the kyanite-andalusite-sillimanite equilibrium curves and triple point (Figure 6, curves 3A, 3B). His work shows that andalusite probably crystallized metastably for about 100°C above its stability field in the work carried out by Khitarov _et al_., (1963) but that andalusite does have an extensive stability field. It appears that in this case the viewpoint expressed by Khitarov _et al_. is not wholly valid and that Weill and Fyfe's work is completely invalid. This neatly illustrates the perils of both an inadequate experimental approach and of a purely theoretical approach.

Schreyer and Yoder (1960, p. 147-152; 1959, p. 100-104) have investigated the system Mg-cordierite and water and have determined the breakdown curve

(Figure 6, curve 5A) and the curve for the beginning of melting (Figure 6, curve 5B). They reversed the breakdown reaction (at low water pressure; cordierite + vapour $\longrightarrow$ pyrophyllite + amesite + vapour), indicating that the breakdown curve is an equilibrium curve. In using this data there are problems related to bulk composition. Natural cordierites contain some iron, which will affect their stability range. Schreyer and Yoder investigated this factor by synthesizing Fe-cordierite and tentatively concluded (1959, p. 103) that iron does not greatly change the lower stability limits of cordierite, although it does lower the melting curve. Another problem is that in natural assemblages containing much K_2O, pyrophyllite would be replaced by muscovite and the reaction would be: muscovite + chlorite + quartz $\longrightarrow$ cordierite + phlogopite (biotite). Schreyer and Yoder (1959, p. 103-104) suggest that this reaction would take place at higher temperatures than the chlorite (amesite) +pyrophyllite reaction. It is obvious that although the boundary curve for the reaction cordierite + vapour $\longrightarrow$ pyrophyllite + amesite + vapour represents equilibrium, a natural assemblage containing cordierite may have formed under somewhat different temperature and pressure conditions that this curve would indicate.

Greenwood (1963, p. 317-351) synthesized pure magnesium anthophyllite in the presence of excess water (i.e. uncombined water) and established its upper and lower stability limits by reversible experiments (Figure 6, curves 6A, 6B). Application of his results to natural assemblages must be made with caution because of the presence of Fe and/or Al in most natural members of the anthophyllite-gedrite series. A more serious problem, however, is the fact that anthophyllite has a much larger stability field in the absence of uncombined water - the "water-deficient region" (Yoder, 1952). In areas where metamorphism has occurred under water-deficient conditions this could lead to major errors in determining pressure-temperature conditions.

In addition to the stability fields for single minerals, stability fields for

mineral assemblages may be established. Segnit and Kennedy (1961) studied the assemblage muscovite + quartz and its reaction products. They present curves for reactions starting with initial compositions of $K_2O.3Al_2O_3.6SiO_2 + 4SiO_2 + H_2O$ and $K_2O.3Al_2O_3.6SiO_2 + 12SiO_2 + H_2O$ at pressures above 5 kilobars. The upper stability limit of muscovite is 30°C lower with the second initial composition. This type of work can be useful if the natural assemblage being considered is very close in composition to the experimental assemblage but even then it can only give approximations of PT conditions. However, it is of little use otherwise. For example, biotite and phlogopite are stable to much higher temperatures than muscovite. The presence of a little Fe or Mg in natural muscovite would probably appreciably shift the boundary curve which Segnit and Kennedy have established.

Two other types of curves have been used as boundary curves for stability fields. These are curves showing the beginning of fusion and the temperature of complete melting for mineral assemblages. The beginning of fusion is the more useful. It varies with composition (including water content), but over a fairly narrow range (at high pressures). The temperature of complete melting is, by definition, outside of the range of metamorphic processes. It is strongly dependent on water content and bulk composition and cannot be used with any degree of certainty.

In the preceding discussion, it has been tacitly assumed that only three variables, temperature, pressure, and bulk composition, control the mineral assemblages which will be present in a given metamorphic rock. However, stress, load pressure (P_{load}), water pressure (P_{H_2O}), carbon dioxide pressure (P_{CO_2}), and pressures due to oxygen (P_{O_2}) and other volatiles may be more or less independent variables and may affect a given reaction differently. The writer will ignore the partial pressures of volatiles other than water in the following discussion. Carbonate-containing assemblages are rare in the thesis area, and carbonate minerals were probably never major constituents of any abundant rock type. The method of analysis used does not permit a

distinction between ferric and ferrous iron, so that a discussion of P_{O_2} is not possible. Eugster (1959, p. 397) states that higher degrees of metamorphism than those necessary to produce a slate do not seem to produce any trends in the state of oxidation of mineral assemblages.

The relationship of P_{H_2O} to P_{load} has been considered by a number of authors. Yoder (1955) in an extensive paper on this topic, comes to the following conclusions (p. 516),

> "A univariant curve marking one high grade reaction running at $P_{H_2O} < P_{rock}$ (= P_{load}) may actually lie at lower pressures and temperatures than one of lower grade taking place at $P_{H_2O} = P_{rock}$.....Because the sequence (of isograds) is normal in so many areas, it appears as though metamorphism took place in a water-pressure gradient common to all beds. The two water-pressure gradients that would be common are the hydrostatic gradient, and lithostatic gradient. Of these the lithostatic gradient, where $P_{H_2O} = P_{rock}$, is most probable...One may apply the univariant curves determined in the laboratory at $P_{H_2O} = P_{rock}$ to most regional metamorphic problems, either as approximations of the upper limiting conditions or in establishing the sequence of mineral changes at a fixed partial water pressure."

Fyfe, Turner, and Verhoogen (1958, p. 81), on the basis of the regularity of mineral paragenesis in metamorphic terranes, conclude that fluid pressure is largely dependent on load pressure and that the relation $P_{fluid} \simeq P_{load}$ may be accepted as a first approximation. In the area under discussion, P_{CO_2} was probably very small, so that as an approximation $P_{H_2O} \simeq P_{load}$.

Miyashiro (1961, p. 286) has suggested the P_{H_2O} may be, in some cases, less than P_{rock} (=P_{load}). This is based on experimental data which shows that at $P_{H_2O} > 4$ kilobars, pyrophyllite is stable to 600°C, and if $P_{H_2O} = R_{rock} > 4$ kilobars, quartzo-feldspathic rocks would begin to melt at about 600°C. He states that pyrophyllite and such quartzo-feldspathic rocks do not occur together in ordinary metamorphic terranes and hence $P_{H_2O} < P_{rock}$. However, under the conditions postulated pyrophyllite would alter to muscovite in the presence of potassium, and this would be available in most cases of partial melting of quartzo-feldspathic rocks. Hence Miyashiro's argument is probably not valid. In the subsequent

discussion the writer, following Yoder (1955) and Fyfe, Turner, and Verhoogen (1958), will make the assumption that P_{load} approximates P_{H_2O}, and for graphical purposes will assume that $P_{load} = P_{H_2O}$.

With regard to stress, Fyfe, Turner, and Verhoogen (1958, p. 181, footnote) state

> "Stress, which depends on properties of individual rocks, is a variable which could differ locally by considerable amounts. As a facies comprises rocks which are closely associated in the field it is possible that a given facies might include rocks that were subjected to similar conditions of load and fluid pressure and temperature but not necessarily to equal stress."

As a given mineral facies is not necessarily related to a given stress, and as the effects of stress and load pressure are not distinguishable (apart from the fact that an alignment of minerals probably indicates some directional pressures), the question of stress is most difficult to consider. Clark (1961, p. 647-648) suggests that perhaps a tectonic overpressure due to stresses in the order of one kilobar could persist for a few thousand years. For purposes of discussion the writer will accept one kilobar as being of the right order of magnitude for maximum tectonic overpressures.

A major problem with regard to bulk composition of a rock is the question of its water content at the time of metamorphism. For a number of minerals, for example anthophyllite, the stability field differs considerably in assemblages which have excess (uncombined) water and those which are water-deficient. Yoder (1952, 1955) considers this problem and concludes that mineral assemblages regarded as belonging to different metamorphic facies may have formed under the same temperature-pressure conditions but in the presence of different amounts of water. Fyfe, Turner and Verhoogen (1958, p. 16-19) sharply criticize Yoder's viewpoint and his interpretation of his experimental results. It is their view that in general metamorphic systems are open to water, as is shown by the fact that progressive metamorphism of individual rock bodies is accompanied by notable change in water

content. Yoder (1955, p. 518) and Fyfe, Turner, and Verhoogen (1958, p. 188-189) agree that argillaceous rocks originally contained enough water for formation of the most hydrous metamorphic assemblages. They also agree that some other rocks, for example, arkose (Yoder) and greywacke and basic igneous rocks (Fyfe, Turner, and Verhoogen) may not contain enough original water to form the assemblages appropriate under given temperature-pressure conditions. Fyfe, Turner, and Verhoogen suggest that generally the excess water required to form the appropriate assemblages comes from zones of higher grade metamorphism and from juvenile water. Yoder suggests that the rocks may remain water deficient and the result is a mineral assemblage generally regarded as indicating another metamorphic facies. In the thesis area, several important assemblages are probably derived from argillaceous rocks, and these presumably contained excess water and hence are good temperature-pressure indicators. Other rocks which might have been water-deficient, such as meta-arkose, contain abundant hydroxyl-containing minerals (micas and amphiboles) and, moreover, generally have mineral assemblages regarded as indicating the same or a closely similar metamorphic facies to the mineral assemblages in the argillaceous rocks. It is concluded that, in general, there probably was excess water in the thesis area during metamorphism.

EXPERIMENTAL DATA EMPLOYED

All the experimental data used is tabulated below. The numbers assigned to boundary curves are used on Figure 6. For strongly temperature-dependent reactions the phase or phases stable at lower temperatures are given on the left in equations.

1. Equilibrium curve between sillimanite (lower pressures) and kyanite (higher pressures). After Clark (1961, p. 646, fig. 3). See previous discussion.

2. Relationship between kyanite, sillimanite, andalusite and mullite + quartz. Boundary curves may define fields of metastable crystallization instead of being equilibrium curves; 2A, kyanite (high pressure), sillimanite (low pressure); 2B, andalusite (low temperature), sillimanite (high temperature); 2C, sillimanite (high pressure), mullite + quartz (low pressure); 2D, andalusite (low temperature),

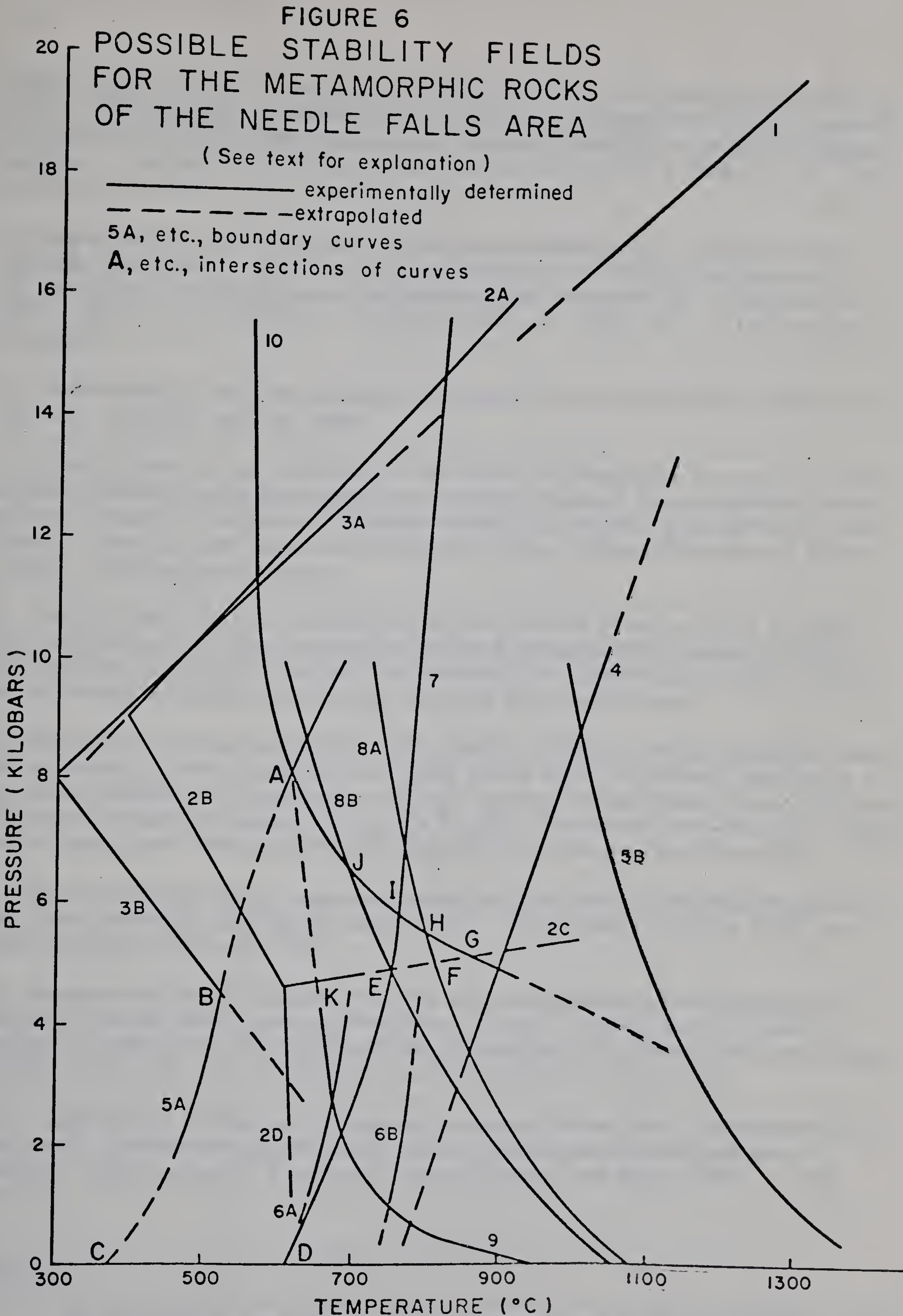


FIGURE 6
POSSIBLE STABILITY FIELDS FOR THE METAMORPHIC ROCKS OF THE NEEDLE FALLS AREA
(See text for explanation)
experimentally determined
extrapolated
5A, etc., boundary curves
A, etc., intersections of curves
PRESSURE (KILOBARS)
TEMPERATURE (°C)
1
2A
3A
10
7
4
8A
8B
2B
3B
5B
2C
5A
2D
6A
6B
9
A
B
C
D
E
F
G
H
I
J
K
0
2
4
6
8
10
12
14
16
18
20
300
500
700
900
1100
1300

mullite + quartz (high temperature). Kyanite-andalusite-sillimanite triple point at 390°C, 9000 atmospheres (≅9000 bars). Andalusite-sillimanite-mullite (+ quartz) triple point at 600°C, 4500 atmospheres. Curves 2C and 2D are only first approximations. After Khitarov, Pugin, Chao, and Slutskii (1963, p. 238, fig. 4). See previous discussion.

3. Relationships between kyanite, sillimanite and andalusite. Boundary curves represent equilibrium. 3A; Kyanite (high pressure), sillimanite (low pressure). 3B; andalusite (low temperature), sillimanite (high temperature). Triple point at 300° ± 50°C, 8 ± 0.5 kilobars. After (Bell 1963, p. 1055, fig. 1). See previous discussion.

4. Upper stability limits for almandite. Given in Yoder and Chinner (1960, p. 81, fig. 26). Original work by Yoder.

5. Stability field of Mg-cordierite in the system Mg-cordierite + water; 5A, equilibrium breakdown curve to pyrophyllite + amesite + vapour (lower pressures) and to chlorite + quartz + corundum (higher pressures); 5B, beginning of melting of cordierite. After Schreyer and Yoder (1960, p. 93, fig. 34) and Schreyer and Yoder (1959). See previous discussion.

6. Stability field for Mg-anthophyllite in the presence of excess SiO_2 and H_2O; 6A, equilibrium curve for the reaction talc $\longrightarrow$ anthophyllite + quartz + H_2O; 6B, equilibrium curve for the reaction anthophyllite $\longrightarrow$ enstatite + quartz + H_2O. After Greenwood (1963, p. 332, fig. 3). See previous discussion.

7. Reactions in the system $K_2O.3Al_2O_3.6SiO_2$ + $4SiO_2$ + H_2O; equilibrium curve for muscovite + quartz $\longrightarrow$ muscovite + glass (above about 5 kilobars); muscovite + quartz $\longrightarrow$ sanidine + sillimanite (or mullite) + quartz + water (below about 5 kilobars). For the first reaction pressure is P_{load} ($> P_{H_2O}$). For second reaction $P_{load} = P_{H_2O}$. After Segnit and Kennedy (1961, p. 284, fig. 2). See previous discussion.

8. Beginning of melting of amphibolites derived from natural basalt-water systems; 8A, hawaiite-H_2O; 8B, high Al basalt-H_2O. After Yoder and Tilley (1962, p. 454, fig. 30; p. 451, fig. 28).

9. Pressure-temperature projection of the solidus (beginning of melting) of the Westerly, Rhode Island, granite; the Quincy, Mass., granite; and the isobaric minimum in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O. After Tuttle and Bowen (1958, p. 83, fig. 43). Projection of curve based on p. 122, fig. 62.

10. Beginning of melting for a composite sample collected from a sandstone-shale sequence. Sample composition intermediate between granodiorite and quartz diorite. Water content 3.2 per cent. After Khitarov and Pugin (1962, p. 345, fig. 2).

RESULTS

As indicated in the first part of this chapter, most of the metamorphic rocks of the thesis area belong to the amphibolite facies and to mineral zones B and C of Miyashiro (1961). The biotite-cordierite-sillimanite-garnet rocks, which belong

to mineral zone C, will be considered first. If the assemblage biotite-cordierite-garnet-microcline-plagioclase-sillimanite-quartz is truly in equilibrium, the field in which it is stable (see Figure 6) is approximately defined by curves 1, 3A, 3B to the right of 5A, 2C, 5A above 3B, and part of 4 and 5B, assuming that; (1) curve 2C (sillimanite $\rightleftharpoons$ mullite + quartz) does represent equilibrium; (2) the garnet is essentially almandine; and (3) that $P_{load} = P_{H_2O}$. Curves 1, 2C, 3A and 3B bound the stability field of sillimanite, curves 5A and 5B bound the stability field of cordierite, and curve 4 is the upper stability limit of almandine. Schreyer and Yoder (1959, p. 102) suggest that cordierite may not be stable at P_{H_2O} slightly higher than 10 kilobars. This gives a maximum pressure for the cordierite-bearing rocks, here taken to be about 12 kilobars. Curves 9 and 10 (partial fusion curves) are of some help in delineating the stability field of the cordieritic rocks if one considers the following facts: (1) the predominant rocks in the assemblage were argillaceous, suggesting that they contained abundant water originally; (2) pegmatitic pods occur in the cordieritic rocks, although rarely, but were not noted in the quartzo-feldspathic interlayers; and (3) the quartzo-feldspathic interlayers show no evidence of intrusion into the ordinary cordieritic rocks, or of any sort of re-mobilization.
The presence of the pegmatitic pods in the cordieritic rocks suggests a temperature exceeding curve 9 (partial fusion curve for a system with excess water) for at least part of the assemblage. The rarity of the pods suggests the whole of the assemblage may not have crystallized at temperatures above curve 9 or did not contain excess water. The lack of mobilization of the quartzo-feldspathic layers is presumably due to these rocks not being water saturated. Some of these layers are only about six inches thick, so that they must have acquired some water from the normal cordieritic rocks. Assuming that this amount of water was close to that for the rocks used in constructing curve 10 (about 3 per cent) the stability field for the biotite-cordierite-garnet-sillimanite rocks should lie to the left of curve 10.

If all these assumptions are combined the stability field for some of the cordieritic rocks is probably bounded by AKG on Figure 6. Some of these rocks probably formed in the stability field ABK. Field AKG lies between 610 and 860°C and 4.75 and 8 kilobars. Field ABK lies between 520 and 650°C and 4.4 and 8 kilobars. These fields are bounded, on the low temperature and low pressure sides, by the limits of stability of sillimanite and cordierite. They are bounded by partial fusion curves on the high temperature side. It should be emphasized that these figures are valid only if the experimental data represents equilibrium curves and the assumptions made in the use of the partial fusion curves are reasonable. Even if this is so the boundaries of the stability fields are by no means as exact as the figures quoted would indicate. The minimum pressure is based solely on curve 2C (sillimanite $\rightleftharpoons$ mullite + quartz) and its extrapolation to point B. As this curve may represent metastable crystallization the stability field for this assemblage may extend to zero pressure between point C and the extension of curve 4 or curve 9. The amphibolites belonging to mineral zone C in most cases show no evidence of flowage or partial melting, so that presumably they were at temperatures below curve 8A or 8B (partial fusion of amphibolites). This gives temperature limits of HF or JE for mineral zone C assuming that curve 2C is valid. To summarize, the rocks belonging to mineral zone C in the thesis area have a fairly reliable minimum temperature of formation of about 520°C, a possible maximum temperature of formation of between perhaps 760° and 860°C, a possible maximum pressure of formation of about 8 kilobars, and a possible minimum pressure of formation of about 4.4 kilobars.

The only minerals in the rocks belonging to mineral zone B which provide any evidence of pressure – temperature conditions are andalusite and muscovite. Andalusite is not stable above about 8 kilobars (Bell, 1963), giving a maximum pressure which is the same as that inferred for mineral zone C on different evidence. Andalusite does not, however, provide much evidence concerning temperature. The

extrapolated part of curve 3B (andalusite $\rightleftharpoons$ sillimanite) suggests that it can exist at temperatures above the partial melting curve for water - saturated granite (curve 9) at pressures of less than 2 kilobars. If curve 2D is valid, the maximum temperature at which andalusite is stable would be about 620°C. The upper stability limit for muscovite (curve 7) gives an approximate maximum temperature of 720°C for mineral zone B.

The anthophyllite-bearing disequilibrium assemblage M is of interest, because it may indicate local development of temperatures in the field bounded by curves 6A and 6B after most or all of the deformation had occurred. However, in view of the unknown role of Fe and Al in promoting the stability of anthophyllite and its larger stability field in the water-deficient region this is highly speculative.

By assuming a value for the density of the rocks, depth of burial and the geothermal gradient may be calculated. Assuming an average density of about 2.8 gm/cm^3 (Mason, 1958, p. 41), 1 kilobar $\approxeq$ 3.5 kilometers. If a maximum pressure of 8 kilobars is accepted, this indicates a maximum depth of burial for the rocks of the map area of about 28 kilometers if the stress was zero or of 25 kilometers if the stress was one kilobar. The present average thickness of the continental crust of North America is about 36 to 40 kilometers (Jacobs, Russell and Wilson, 1959, p. 344) and the thickness in orogenic belts may be considerably greater. This suggests that these figures are in the right order of magnitude.

The minimum geothermal gradient for the rocks of mineral zone C can be calculated from the equilibrium curve (5A) for the reaction which defines the lower stability limit for Mg-cordierite. This value is 22°C/km (stress = 0) to 24°C/km (stress = 1 kilobar). Modern measurements of the geothermal gradient average close to 30°C/km but range from 7°C/km to 50°C/km (Turner and Verhoogen, 1951, p. 352). Considering all the uncertainties in the data, the agreement between these figures and the minimum gradient for the thesis area seems to be reasonably good.

Chapter VI

RADIOMETRIC DATING

Introduction

Two types of dating[1] have been carried out for rocks of the thesis area. These are K-Ar dating of mineral separates and Rb-Sr dating of whole rock samples. Sample locations are shown on Figure 7. Micas, and particularly biotite, can be expected to lose their radiogenic argon during amphibolite facies metamorphism (Godfrey and Baadsgaard, 1962) and hence K-Ar apparent ages of these date the period of metamorphism. Hornblendes appear to be affected to a lesser degree by metamorphic events (Hart, 1961) and hence may provide minimum ages for older events. Rb-Sr whole rock ages are unaffected by metamorphism in the ideal case in which the rock as a whole is a closed system. In this case, for igneous rocks the Rb-Sr whole rock apparent age is the age of consolidation and for metamorphosed sedimentary rocks it should be intermediate between the age of the source material and the age of deposition and/or lithification (Whitney and Hurley, 1963).

K-Ar dating

The nuclide K^{40} decays in two different ways to daughter nuclides, Ca^{40} and Ar^{40}. The former is a product of β-decay and the latter of K electron capture. In the latter case an active form of Ar^{40} is obtained which gives off γ-rays to reach a more stable state. The decay constants used in this thesis are

$$\lambda_e = 0.589 \times 10^{-10}/\text{yr} \qquad (\text{decay to } Ar^{40})$$

$$\lambda_\beta = 4.76 \times 10^{-10}/\text{yr} \qquad (\text{decay to } Ca^{40})$$

The age of a mineral may be obtained by use of the formula:

$$\text{Time } (t) = \frac{1}{\lambda_e + \lambda_\beta} \ln \left[\frac{N_t\, Ar^{40}}{N_t\, K^{40}} \left(\frac{\lambda_e + \lambda_\beta}{\lambda_e} \right) + 1 \right]$$

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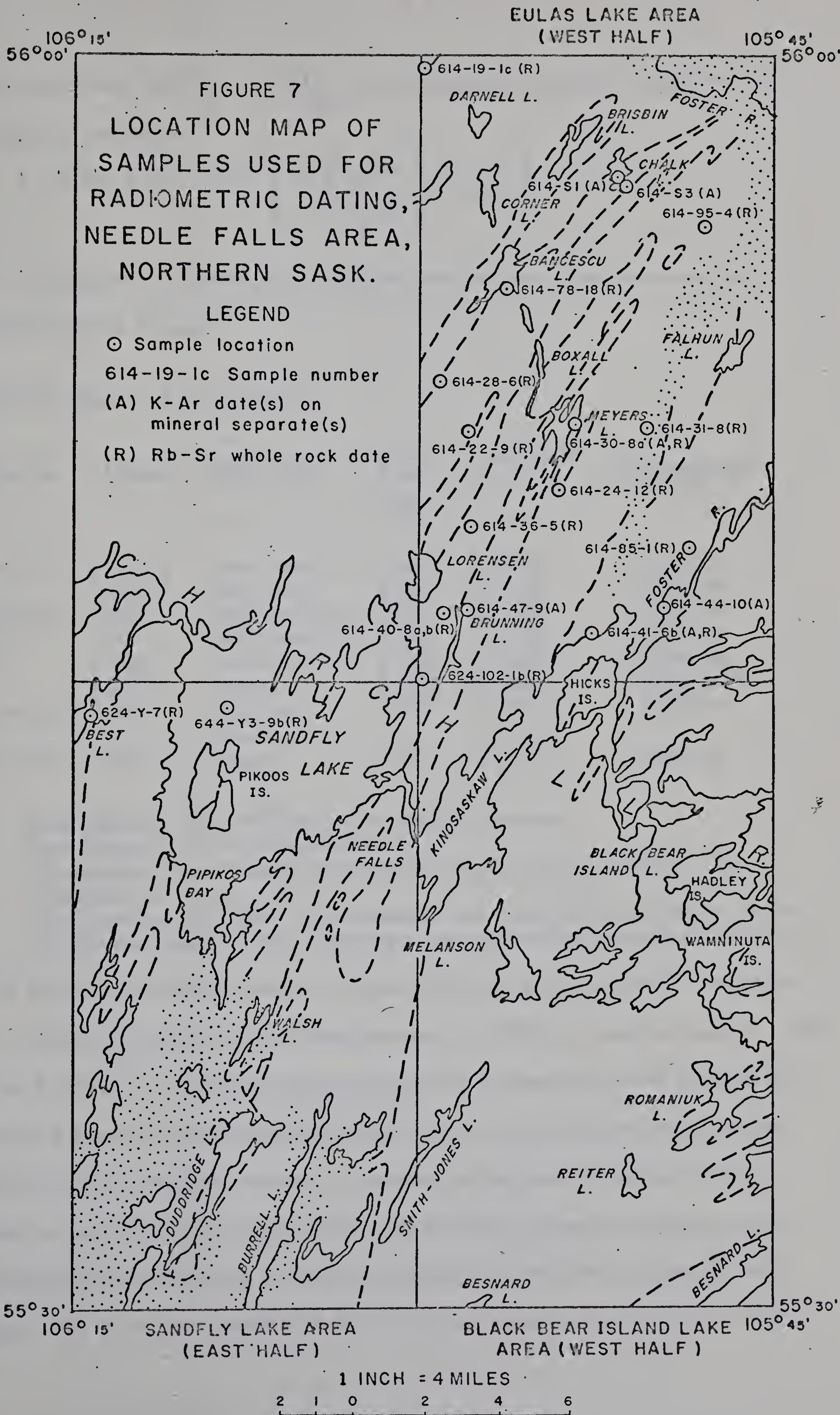
[1] Sample preparation and experimental data for K-Ar dating and Rb-Sr dating are discussed in Appendices V and VI respectively.


EULAS LAKE AREA
(WEST HALF)
106° 15'
56° 00'
105° 45'
56° 00'
FIGURE 7
LOCATION MAP OF SAMPLES USED FOR RADIOMETRIC DATING, NEEDLE FALLS AREA, NORTHERN SASK.
LEGEND
⊙ Sample location
614-19-1c Sample number
(A) K-Ar date(s) on mineral separate(s)
(R) Rb-Sr whole rock date
614-19-1c (R)
DARNELL L.
BRISBIN L.
FOSTER R.
CHALK L.
614-S1 (A)
614-S3 (A)
614-95-4 (R)
CORNER L.
BANCESCU L.
614-78-18 (R)
FALHUN L.
BOXALL L.
614-28-6 (R)
MEYERS L.
614-31-8 (R)
614-30-8a (A,R)
614-22-9 (R)
614-24-12 (R)
614-36-5 (R)
614-85-1 (R)
LORENSEN L.
FOSTER
614-47-9 (A)
614-44-10 (A)
614-40-8a,b (R)
BRUNNING L.
614-41-6b (A,R)
624-102-1b (R)
HICKS IS.
624-Y-7 (R)
644-Y3-9b (R)
BEST L.
SANDFLY LAKE
PIKOOS IS.
KINOSASKAW L.
NEEDLE FALLS
PIPIKOS BAY
BLACK BEAR ISLAND L.
HADLEY IS.
MELANSON L.
WAMNINUTA IS.
WALSH L.
ROMANIUK L.
REITER L.
DUDDRIDGE L.
BURRELL L.
SMITH-JONES L.
BESNARD L.
55° 30'
106° 15'
SANDFLY LAKE AREA
(EAST HALF)
BLACK BEAR ISLAND LAKE AREA (WEST HALF)
105° 45'
1 INCH = 4 MILES
2 1 0 2 4 6

For the values used for λ_e and λ_β, and changing the natural logarithm (ln) to a $\log_{10}$ this becomes

$$t = 4.308 \times 10^9 \quad \log \left[1 + \left(\frac{Ar^{40}}{K^{40}} \right) (9.08) \right]$$

The results of K-Ar dating of samples from the thesis area are shown in Table XVII and on Figure 8.

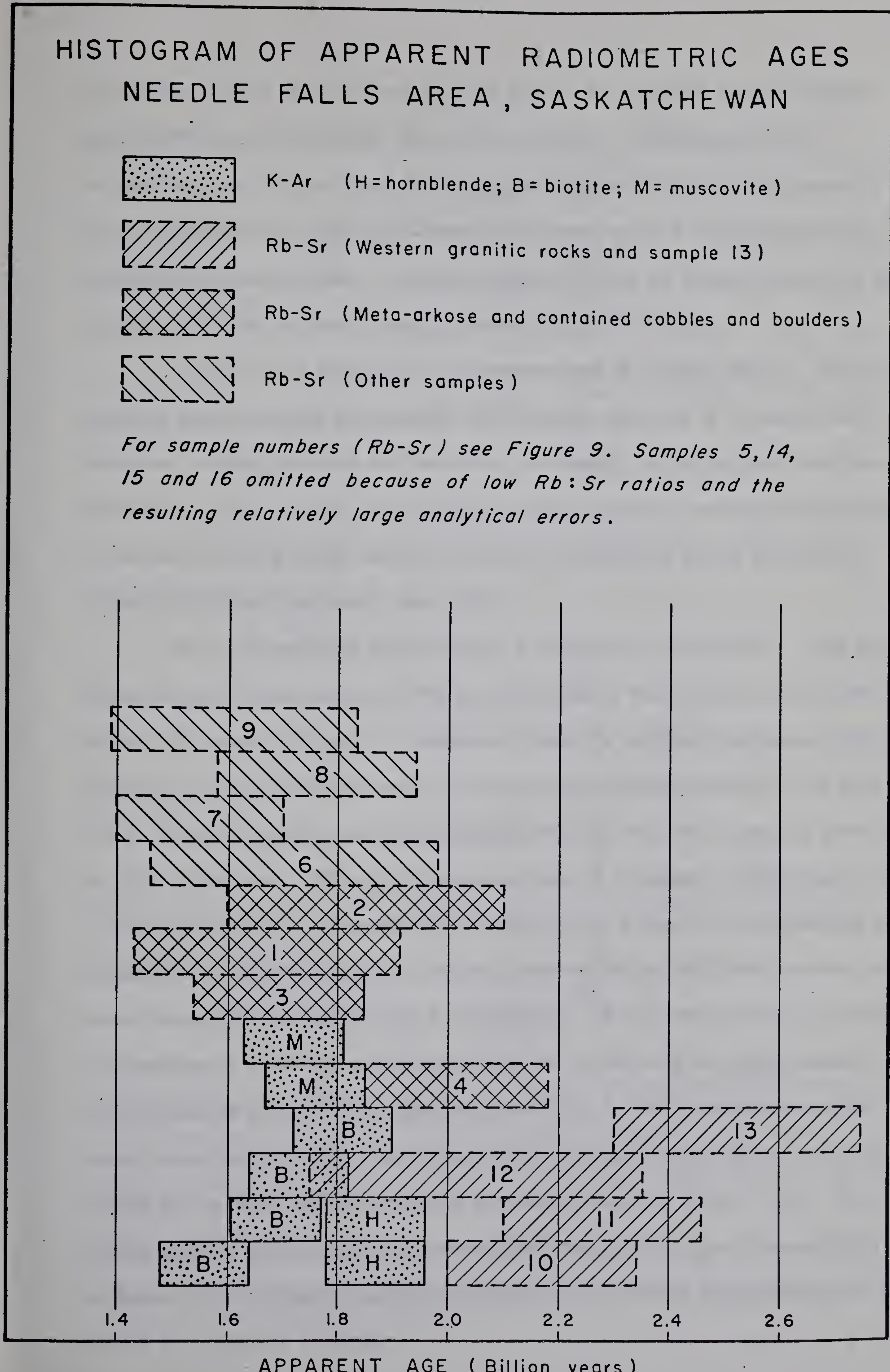
Table XVII: Results of K-Ar dating.

Sample No.	Mineral	Rock type	K_2O[2] (%)	Ar^{40}/K^{40}[2]	Apparent age (b.y.)[3]
614-47-9	Musc.	Biot.-musc.	9.395	0.1719	1.76±0.09
	Biot.	qtz. sch.	8.024	0.1794	1.81±0.09
614-30-8a	Musc.	Meta-arkose	10.23	0.1653	1.72±0.09
614-S3	Biot.	Hrn.-biot. gn.	7.013	0.1435	1.56±0.08
614-S1	Biot.	Granitic	8.066	0.1670	1.73±0.09
	Hrn.	gneiss	1.053	0.1883	1.87±0.09[4]
614-44-10	Hrn.	Hrn. qtz. diorite	1.095	0.1884	1.87±0.09
614-41-6b	Biot.	Pegm.	7.321	0.1610	1.69±0.08

[1] See Appendix VII and Figure 7 for sample locations.
[2] See Appendix V for more details.
[3] A precision (one standard deviation) of ±5 per cent is assumed. See Appendix V.
[4] K_2O content, Ar^{40}/K^{40}, and apparent age corrected for a biotite content of different apparent age. Apparent age without the correction is 1.84 b.y.

Five of the six mica samples have K-Ar ages which are the same within analytical error. The mean value of age for these samples is 1,740 m.y. and the range is 1,690 m.y. to 1,810 m.y. Three of these micas are from metamorphic rocks and undoubtedly give the age of regional metamorphism connected with the last major orogeny (Hudsonian) which affected the area. The mica in the granitic gneiss, which is probably a gneissic facies of the western granitic rocks, gives the same age as the metamorphic micas and hence is either metamorphic or has been up-dated by this orogeny. The mica from sample 614-41-6b is from an undeformed pegmatite which

FIGURE 8


HISTOGRAM OF APPARENT RADIOMETRIC AGES
NEEDLE FALLS AREA, SASKATCHEWAN
K-Ar (H=hornblende; B=biotite; M=muscovite)
Rb-Sr (Western granitic rocks and sample 13)
Rb-Sr (Meta-arkose and contained cobbles and boulders)
Rb-Sr (Other samples)
For sample numbers (Rb-Sr) see Figure 9. Samples 5, 14, 15 and 16 omitted because of low Rb : Sr ratios and the resulting relatively large analytical errors.
9
8
7
6
2
1
3
M
M
4
B
13
B
12
B
H
11
B
H
10
1.4
1.6
1.8
2.0
2.2
2.4
2.6
APPARENT AGE (Billion years)

is probably related to the eastern granitic rocks. Its somewhat younger apparent age (1,690 m.y.) may be real rather than analytical. The pegmatite and surrounding granitic rocks show little evidence of granulation and the pegmatite lacks foliation so that it probably formed after most or all of the folding which accompanied metamorphism. The other dated micas are all aligned parallel to schistosity or foliation and were probably formed during the folding.

The sixth mica sample gives an apparent age of 1,560 $\pm$ 80 m.y. This has probably been up-dated by movement and shearing along one of the major north-northwest trending faults of the thesis area, or possibly by the action of solutions travelling along this fault. The evidence is not conclusive, and the sample appears to be fresh, but the sample locality is known to be close to one of these faults (Chalk Lake,Eulas Lake Area, West Half).

The two hornblende separates give K-Ar ages of 1,870$\pm$90 m.y. The minimum value for these samples (1,780 m.y.) is close to the average value for the mica K-Ar dates (1,740 m.y.). However, there is a sufficient discrepancy that attribution of the hornblende ages to the Hudsonian orogeny possibly is not fully justified. Greater apparent ages for hornblende than for mica are commonly encountered in K-Ar dating work. Where this feature occurs, it is generally interpreted as indicating that the area concerned has been affected by a thermal or metamorphic event subsequent to initial formation of the mica and hornblende and that the mica has been more thoroughly "up-dated" than the hornblende. If this interpretation is adopted the hornblende K-Ar ages are minimum ages for formation of the granitic gneiss and hornblende quartz diorite. Another possibility is that hornblende may gain excess argon given off by surrounding minerals, as suggested by Damon and Kulp (1958) and as shown to be the case for pyroxenes (Hart and Dodd, 1962). This would result in apparent ages which are older than the true age. The available evidence from the thesis area does not permit any conclusion to be reached as to which interpretation is correct.

Rb-Sr dating

INTRODUCTION

The isotope Rb^{87} decays to Sr^{87} by β-decay. The decay constant adopted in this thesis is $1.47 \pm 0.03 \times 10^{-11}$/yr (Glendinen, 1961). A problem in using the decay of Rb^{87} to Sr^{87} in determining age is the presence of Sr^{87} in normal strontium. This has been corrected for, in this thesis, by use of an isochron plot. Let the subscript o denote the time at which a rock first became a closed system and p denote the present time. Then

$$Rb_o^{87} = Rb_p^{87} e^{\lambda t} \qquad (1)$$

and $$Rb_o^{87} - Rb_p^{87} = Sr_p^{87*} \text{(radiogenic only)} \qquad (2)$$

Combining these equations,

$$Rb_p^{87}(e^{\lambda t} - 1) = Sr_p^{87*} \qquad (3)$$

Considering the change in the total amount of Sr^{87}

$$Sr_p^{87} = Sr_o^{87} + Sr_p^{87*} \qquad (4)$$

Substituting (3)

$$Sr_p^{87} = Sr_o^{87} + Rb^{87}(e^{\lambda t} - 1) \qquad (5)$$

Using the approximation[1] $(e^{\lambda t} - 1) \simeq \lambda t$ and dividing through by Sr^{86}, which is invariant, (5) becomes

$$\left(\frac{Sr^{87}}{Sr^{86}}\right)_p \simeq \left(\frac{Sr^{87}}{Sr^{86}}\right)_o + \left(\frac{Rb^{87}}{Sr^{86}}\right)_p \lambda t$$

If $(Rb^{87}/Sr^{86})_p$ is plotted versus $(Sr^{87}/Sr^{86})_p$ (an "isochron plot") for several rocks of the same age and initial Sr^{87}/Sr^{86} the result is a straight line of slope λt which intersects the Sr^{87}/Sr^{86} axis at $(Sr^{87}/Sr^{86})_o$. The slope of the line gives the age of the rocks.

---

[1] The correction in age because of this approximation is about 2 per cent in 3×10^9 years (Riley and Compston, 1962).

RESULTS

The results of Rb-Sr dating are shown on Figures 8 and 9 and in Table XVIII.

Table XVIII: Estimates of age by the Rb-Sr method (initial Sr^{87}/Sr^{86} ratio assumed to be 0.705 on basis of figure 9).

Number on Fig. 9	Rock type	Rb^{87}/Sr^{86}	Estimated age (b.y.)
1	Meta-arkose	9.74 $\pm$ 1.20	1.64
2	Cobble from meta-arkose	0.987 $\pm$ 0.044	1.85
3	Boulder from meta-arkose	6.58 $\pm$ 0.50	1.68
4	Meta-arkose	8.21 $\pm$ 0.56	1.99
5	Hornblende-biotite gn.	0.513 $\pm$ 0.023	1.72
6	Amphibolite	0.804 $\pm$ 0.036	1.69
7	Acidic meta-volcanic (?) rock	1.47 $\pm$ 0.06	1.57
8	Cord.-biot.-sill.-garn. gn.	3.69 $\pm$ 0.25	1.78
9	Cord.-biot.-sill.-garn. gn.	12.01 $\pm$ 1.74	1.57
10	Western granitic rocks	3.19 $\pm$ 0.14	2.17
11	Western granitic rocks	7.54 $\pm$ 0.56	2.26
12	Western granitic rocks	11.26 $\pm$ 1.36	2.00
13	Western granitic rocks (?)	4.58 $\pm$ 0.37	2.54[1]
14	Eastern granitic rocks	0.116 $\pm$ 0.005	2.34[1]
15	Eastern granitic rocks	0.288 $\pm$ 0.013	1.41[1]
16	Pegmatite	0.319 $\pm$ 0.014	1.28[1]

[1] Meaningless because of low Rb:Sr ratios and the resulting relatively large analytical errors.

The dated samples are believed to indicate two events (A and B), which are represented by isochrons A and B on Figure 9. Event A (~2300 m.y.) is defined by isochron A which passes through the error bars for the three dated samples of the western granitic rocks and a dated sample of a probably related granitic sill (sample 13). Disregarding sample 12, which is highly unreliable because of its low Sr content (see Appendix VI), the minimum age for this event is ~2000 m.y. and the maximum age is ~2750 m.y. (see Figure 8). There are two possible interpretations as to the nature of event A. The first interpretation is that it represents

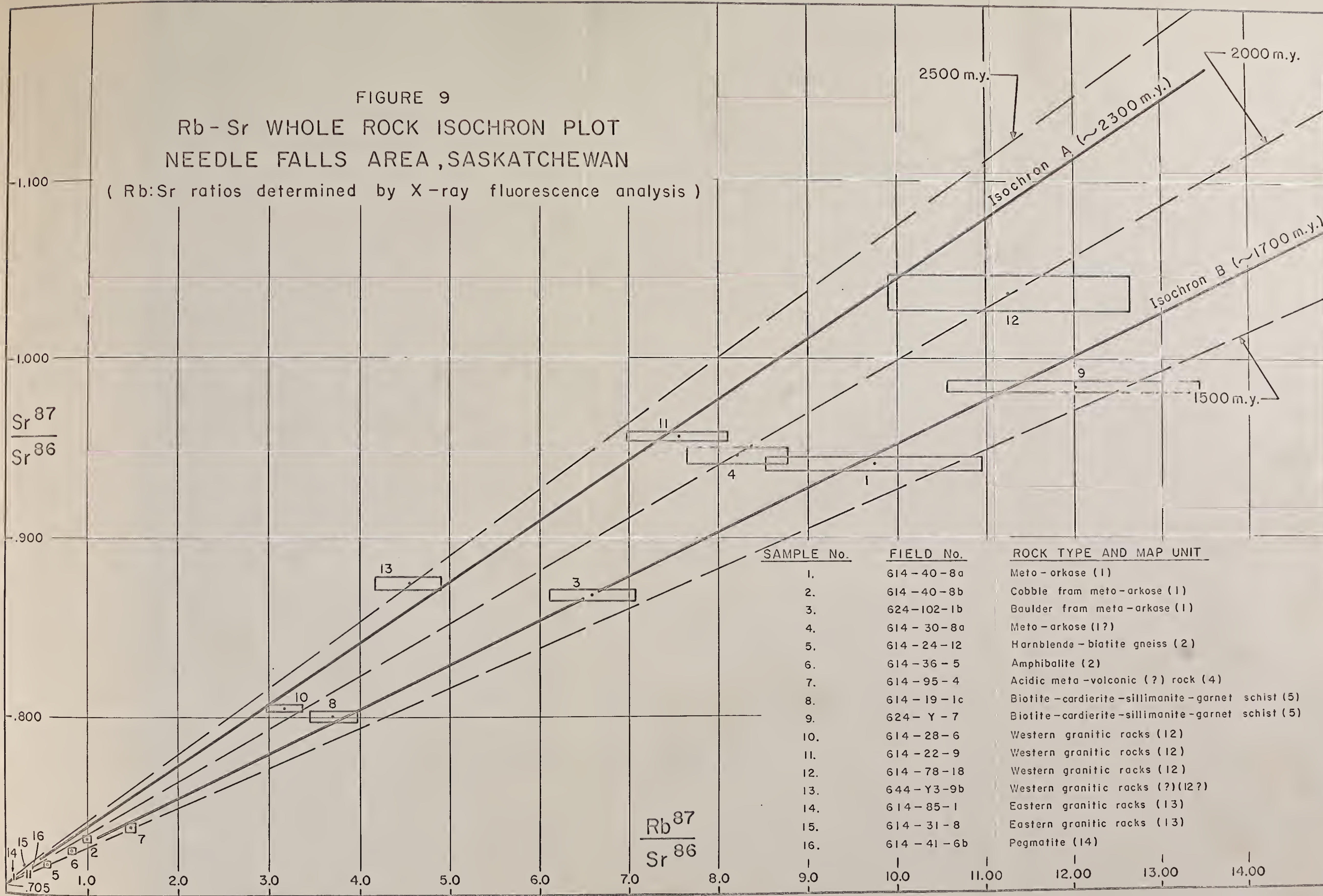


FIGURE 9
Rb - Sr WHOLE ROCK ISOCHRON PLOT
NEEDLE FALLS AREA, SASKATCHEWAN
(Rb:Sr ratios determined by X-ray fluorescence analysis)

SAMPLE No.	FIELD No.	ROCK TYPE AND MAP UNIT
1.	614 - 40 - 8a	Meta - arkose (1)
2.	614 - 40 - 8b	Cobble from meta - arkose (1)
3.	624 - 102 - 1b	Boulder from meta - arkose (1)
4.	614 - 30 - 8a	Meta - arkose (1?)
5.	614 - 24 - 12	Hornblende - biotite gneiss (2)
6.	614 - 36 - 5	Amphibolite (2)
7.	614 - 95 - 4	Acidic meta - volcanic (?) rock (4)
8.	614 - 19 - 1c	Biotite - cordierite - sillimanite - garnet schist (5)
9.	624 - Y - 7	Biotite - cordierite - sillimanite - garnet schist (5)
10.	614 - 28 - 6	Western granitic rocks (12)
11.	614 - 22 - 9	Western granitic rocks (12)
12.	614 - 78 - 18	Western granitic rocks (12)
13.	644 - Y3 - 9b	Western granitic rocks (?)(12?)
14.	614 - 85 - 1	Eastern granitic rocks (13)
15.	614 - 31 - 8	Eastern granitic rocks (13)
16.	614 - 41 - 6b	Pegmatite (14)

the time of initial formation of the western granitic rocks and may date an orogenic episode during which the western granitic rocks were emplaced. The second interpretation is that event A is not truly a single event and that isochron A represents partial "up-dating" of still older rocks, presumably during the Hudsonian orogeny ($\sim$1750 m.y. ago). The second interpretation is considered to be more likely correct as the scatter of points (see Figure 9) is somewhat large to ascribe to analytical error and there is a possibility that the composition of some of the western granitic rocks has been greatly altered by vapours streaming through the rock during subsequent metamorphism (see Chapter IV). Such vapours could selectively remove radiogenic Sr^{87} as this would not be in stable lattice positions. If this interpretation is adopted then the true age of the western granitic rocks may be about 2300 to 2750 m.y. (sample 13).

Event B ($\sim$1700 m.y.) is defined by isochron B on Figure 9. This isochron includes samples 1 to 9 inclusive (except sample 4) within the assumed error. Disregarding the arkosic rocks (samples 1 to 3), the minimum age for this event is $\sim$1400 m.y. and the maximum age is $\sim$2000 m.y. (see Figure 8). For metamorphosed sedimentary rocks, assuming no metasomatism, the apparent age by the Rb-Sr whole rock method should be intermediate between the age of the source material and the age of deposition. The apparent age for arkose, which probably undergoes little chemical breakdown during sedimentation, should be close to the age of the source rock. It is for this reason that the arkosic rocks were excluded in setting age limits for event B. The age of pelites (samples 8 and 9) which consisted in large part of diagenetic minerals, should be close to the age of deposition (Whitney and Hurley, 1963). Volcanic rocks (5?, 6?, 7?) should give the age of volcanic activity. It it is assumed that metasomatism has not affected these rocks, then event B is the age of deposition of the meta-sedimentary rocks and the age of volcanic activity which produced the meta-volcanic (?) rocks. Such sedim-

entation and volcanic activity would have to be related to the Hudsonian orogeny as it took place extremely close in time to metamorphism which is due to that orogeny (see K-Ar dating, this chapter). The alternative interpretation is that event B is a metasomatic event related to the Hudsonian orogeny which resulted in nearly complete "up-dating" of older sedimentary and volcanic rocks. The arkosic rocks provide limited evidence to suggest that the second interpretation is probably correct but that both the "cordierite-garnet rocks" and the "older metamorphic rocks" are younger than the ~2300 m.y. old western granitic rocks and hence are probably related to early phases of the Hudsonian orogeny. The very existence of arkosic rocks containing boulders and cobbles provides evidence for the nearby presence of older granitic rocks. The western granitic rocks are the only known older granitic rocks in the vicinity of the Needle Falls area and hence are a logical source for these arkosic rocks. They are also considered to be a likely source on a chemical basis. The arkosic rocks belonging to the "older metamorphic rocks", the Meyers Lake Group, and the "cordierite-garnet rocks" all have unusually high Na_2O:CaO ratios for arkoses and the western granitic rocks have unusually high Na_2O:CaO ratios for granitic rocks. If the arkosic rocks are derived mainly from the "western granitic rocks" and have been unaffected by later metasomatism, then the dated cobble (sample 2) and boulder (sample 3) should have the same apparent age as the western granitic rocks and the matrix (samples 1 and 4) should appear to be only slightly younger. This is the case with sample 4 and perhaps sample 2, but the other samples lie on isochron B. Hence they have probably undergone metasomatism and isochron B probably indicates a metasomatic event.

Eastern granitic rocks (unit 13)

The probable age of the western granitic rocks and of the major groups of metamorphic rocks have been discussed in the previous sections. The age of the other major unit, the eastern granitic rocks, has not been considered directly. These

rocks have so low an Rb/Sr ratio (Figure 9, samples 14, 15) that they, and their associated pegmatite (Figure 9, sample 16) could not be definitely dated by the Rb-Sr whole rock method. The pegmatite (614-41-6b) has a K-Ar biotite age of 1,690 $\pm$ 80 m.y. which provides a minimum age for the eastern granitic rocks. If the hornblende which occurs in inclusions of hornblende quartz diorite (614-44-10) in the eastern granitic rocks gives the age of the inclusion, it provides a maximum age of 1,870 $\pm$ 90 m.y. for the eastern granitic rocks. The eastern granitic rocks are believed to probably be Hudsonian in age, on the basis of a comparison of their textures and contact features with those of the pre-Hudsonian western granitic rocks. The pre-Hudsonian rocks (Plate XIX, 1 to 4) show granulation throughout, whereas the eastern granitic rocks are only granulated locally and in most cases show little evidence of deformation (Plate XIX, 5 to 8). The contact of the eastern granitic rocks with the metamorphic rocks is a broad and completely gradational transition zone of porphyroblastic gneiss, augen gneiss, and migmatite. The contact of the western granitic rocks is generally a zone of gneissic granitic rocks which may well be mainly a foliated, marginal variant of the granitic rocks themselves.

Inclusions of metamorphic rocks within the western granitic rocks

A number of inclusions of metamorphic rocks occur in the western granitic rocks. Their age is a matter of interest in view of the fact that the main groups of metamorphic rocks are probably younger than the western granitic rocks. These inclusions are not directly date-able by the Rb-Sr method due to unfavourable Rb/Sr ratios. Field relationships are of little value in view of evidence for re-mobilization of the western granitic rocks. Indirect evidence regarding the age of at least some of these metamorphic rocks is provided by Rb-Sr whole rock sample 13 (see Figure 9). This sample is from a granitic sill which forms part of a migmatite whose metamorphic component is predominantly amphibolite. The migmatite occurs within the outcrop

rocks were as low as [illegible] (Figure 6, [illegible]) [illegible] and their [illegible] (Figure 7, [illegible]) [illegible] to be [illegible] by the Rb-Sr whole rock method. The pegmatite [illegible] has a Rb-Sr isochron age of [illegible] m.y. which provides a minimum age for the [illegible] granitic rocks. If the [illegible] which occurs [illegible] of [illegible] (Sample [illegible]) in the western granitic rocks gives the age of the [illegible], it provides a maximum age of [illegible] m.y. for the western granitic rocks. The western granitic rocks are believed to probably be [illegible] on the basis of a comparison of their textural and [illegible] features with those of the pre-[illegible] western granitic rocks. The pre-[illegible] rocks (Plate XIX, [illegible]) are [illegible] throughout, whereas the western granitic rocks are only [illegible] and in most cases show little evidence of deformation (Plate XIX, [illegible]). The contact of the western granitic rocks with the [illegible] rocks [illegible] completely [illegible]. The contact of the western granitic rocks [illegible] a zone of granitic [illegible] rocks which may well be [illegible], [illegible] the granitic rocks themselves.

Inclusions of metamorphic rocks within the western granitic rocks

A number of inclusions of metamorphic rocks occur in the western granitic rocks. Their age is a matter of interest in view of the fact that [illegible] of the [illegible] rocks are probably younger than the western granitic rocks. These inclusions are not directly datable by the Rb-Sr method [illegible]. Field relationships are of little help in view of [illegible] of the western granitic rocks. However evidence regarding the age of at least some of these metamorphic rocks is provided by [illegible]. The [illegible] is from a [illegible] which forms part of a [illegible] composed of [illegible] amphibolite. The [illegible]

area of the western granitic rocks and the sample was chosen, in the field, as a probable example of a minor intrusion related to the western granitic rocks. The sill has an apparent age (Figure 8, Figure 9) which is somewhat greater than the apparent age of the other samples of the western granitic rocks. If the younger apparent age of these other samples is due to up-dating then the sill must have been intruded prior to the up-dating ($\sim$ 2500 m.y. ago) to be protected from it and consequently the amphibolite which it intrudes is at least $\sim$ 2500 m.y. old. If, however, the scatter in apparent age of the western granitic rocks is entirely analytical the sill could be due to re-mobilization related to the Hudsonian orogeny and the amphibolite could actually be younger than the western granitic rocks.

Summary and Conclusions

Rb-Sr whole rock dating indicates that the western granitic rocks were emplaced at least $\sim$ 2300 m.y. ago and perhaps $\sim$ 2500 m.y. ago. Some inclusions in the western granitic rocks may be older but their presence may be due to re-mobilization of the western granitic rocks. The main groups of metamorphic rocks ("older metamorphic rocks", Meyers Lake Group, "cordierite-garnet rocks") are probably younger than the western granitic rocks. Their apparent Rb-Sr whole rock age of $\sim$ 1700 m.y. is probably due to metasomatism related to the Hudsonian orogeny rather than indicating the time of sedimentation and volcanism which formed them. The eastern granitic rocks are believed to be related to the Hudsonian orogeny. They have a minimum age of $\sim$ 1700 m.y. The last strong (Hudsonian) period of metamorphism in the area took place at about 1700-1800 m.y. ago on the basis of K-Ar dating of micas. No post-Hudsonian consolidated rocks have been identified.

Chapter VII

STRUCTURAL GEOLOGY

Folding

EASTERN FOLD BELT

Several types of evidence can be used to deduce the nature of folding in the eastern fold belt. These include outcrop pattern, the orientation of planar features, and the orientation of linear features. As will be shown, these features indicate the nature of the most prominent fold system fairly satisfactorily, but no definitive treatment of other possible fold systems can be carried out.

If outcrop pattern is considered (Figures 16, 17) the most obvious features are the tightness of the folding, the continuity of traces of individual axial surfaces or planes, and the straightness of these traces. The average spacing between traces of axial planes of folds is about one-quarter mile to one mile. The location of major fold axes on Figures 16 and 17 is based on the following evidence and assumptions:

(1) Cross-bedding in quartzites (map-unit 8) at the south end of Duddridge Lake indicates the quartzites overlie quartz-pebble meta-conglomerate (map-unit 7). In the absence of contrary evidence it is assumed that this is the relationship throughout the thesis area.

(2) As no rock type is found above the quartz-pebble conglomerate (map-unit 7) which forms the base of Meyers Lake Group (other than the quartzites and the biotite-muscovite-quartz schist which also belong to this group) the Meyers Lake Group is considered to be the top of the metamorphic sequence and small areas of quartzite or metaconglomerate are considered to be remnants along synclinal axes.

(3) On the maps, (Figures 16 and 17) traces of anticlinal axial planes are considered to lie midway between traces of synclinal axial planes, as defined by outcrops of quartzites and meta-conglomerate, in the absence of evidence of greater structural complexity.

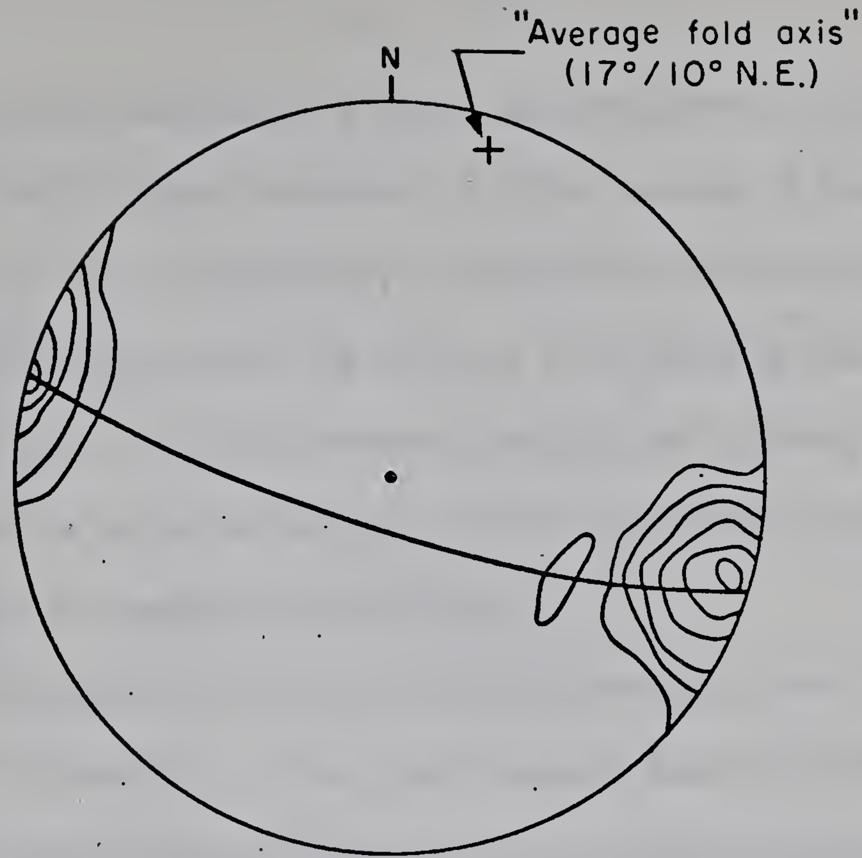
(4) The pebbly meta-arkose which occurs along the centre of the body of meta-arkose (map-unit 1) east of Lorensen Lake, Eulas Lake Area, is assumed to be at or near the bottom of the meta-arkose, and hence to indicate an anticlinal axis. A fold axis must be present here unless the meta-arkose lenses out abruptly to the northeast.

The outcrop pattern also shows that the folds must be doubly plunging. This is particularly obvious in the case of the synclines which are outlined by the quartz-pebble meta-conglomerate (map-unit 7) belonging to the Meyers Lake Group. A cross-warp of some type may occur east of Sandfly Lake and south of the Churchill River, as here contacts are more than usually curved.

Planar features present in the eastern fold belt include bedding and metamorphic foliation. Bedding is recognizable in quartzite (map-unit 8), (see Plate X, 1) and quartz-pebble meta-conglomerate (map-unit 7). Probable bedding occurs in meta-arkose (map-unit 1) and tuffaceous rocks belonging to the acidic meta-volcanic rocks (map-unit 4, see Plate V, 1). The probable bedding takes the form of alternating layers of slightly different colour (see Chapter II). The attitude of bedding and probable bedding in the eastern fold belt is shown on Figure 10A. A concentration of poles to the bedding into a single maximum on this figure indicates that the limbs of the folds are essentially parallel and the folding is isoclinal. Poles to bedding should form a girdle perpendicular to the axial surface and at 90° from the fold axis, in the case of cylindrical folds. The folds of the eastern fold belt are probably cylindrical, rather than conical, on the basis of their general appearance. If this is the case, a girdle can be drawn as shown on Figure 10A, and the average axial surface (not shown) and average fold axis can be predicted. The average axial surface has an azimuth of north 18° east, dip 82° northwest and the average fold axis has an azimuth of 17°, plunge 10° northeast. These azimuths would appear to be reasonable, but the bedding forms so small a maximum and shows so little spread that it is possible to draw several other girdles in Figure 10A, and there is no assurance that the one drawn is correct.

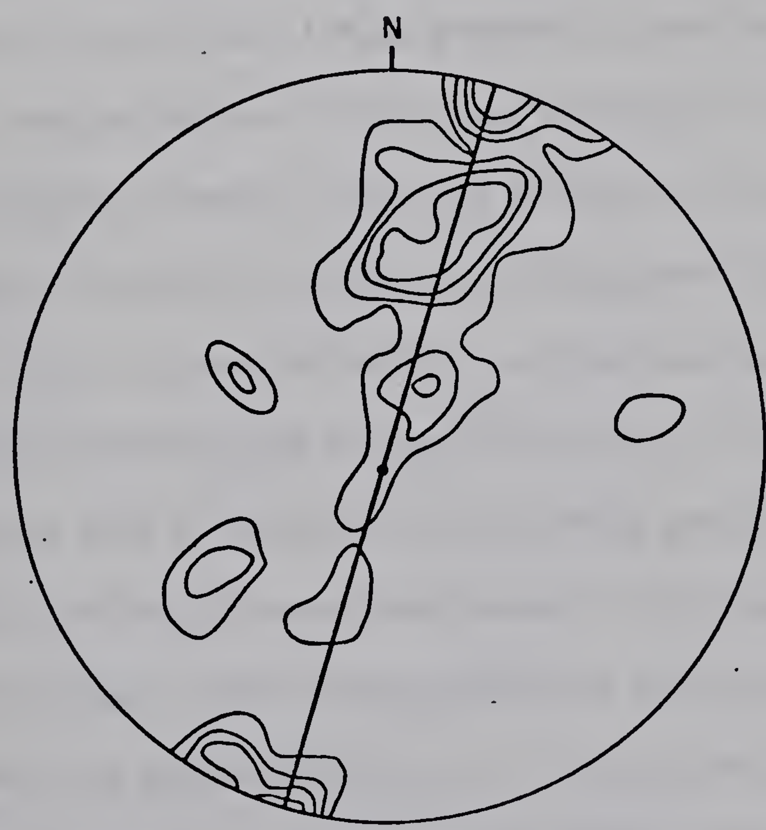
Metamorphic foliation (schistosity and gneissosity) in the eastern fold belt is generally parallel to bedding where the latter is recognizable. In the noses of major folds, however, the metamorphic foliation retains its regional trend and locally

FIGURE 10A



Stereographic projection of poles (122) of bedding and interlayering in quartzite, acidic meta-volcanic (?) rocks, and meta-arkose in the eastern fold belt. Contours 1% - 2% - 5% - 10% - 15% - 20%. Projected from lower hemisphere.

FIGURE 10B



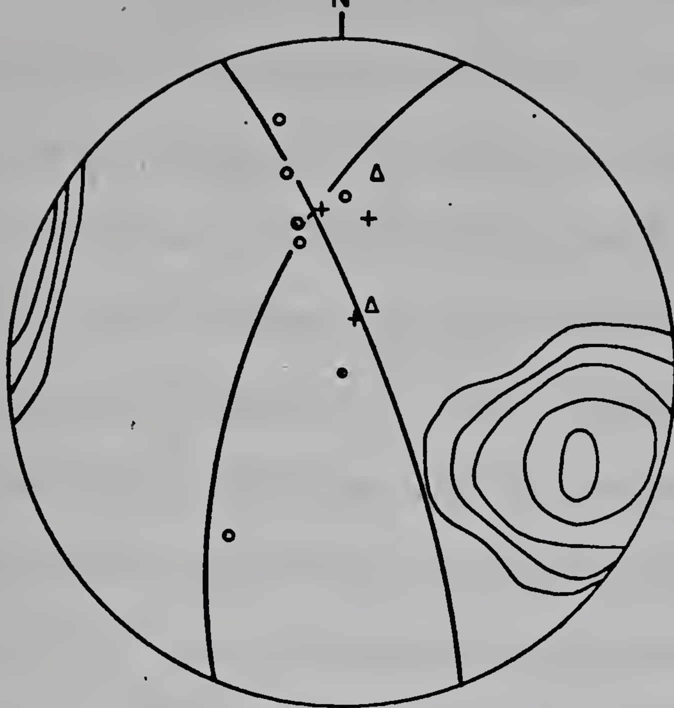
Stereographic projection of axes (91) of minor synclines and anticlines, S- and Z-folds, and crenulations in the eastern fold belt. Contours 1.6% - 2.7% 3.8% - 4.9%. Projected from lower hemisphere.

is perpendicular to contacts between rock types, indicating that it is axial plane foliation rather than bedding plane foliation. In a few outcrops of interlayered quartzites and schist the layering (bedding?) and schistosity (foliation) are not parallel (Plate X, 3), which also suggests that the foliation is not bedding plane foliation. However, in almost every minor fold examined compositional layering and schistosity are parallel. Some of the layers are perhaps original sedimentary layers. If this is the case the schistosity is a bedding plane foliation.

Poles to metamorphic foliation in two comparatively openly folded synclines are shown in Figures 11A and 11B. These figures suggest essentially the same orientation of the average axial surface as Figure 10A but provide no further evidence concerning the nature of the folding.

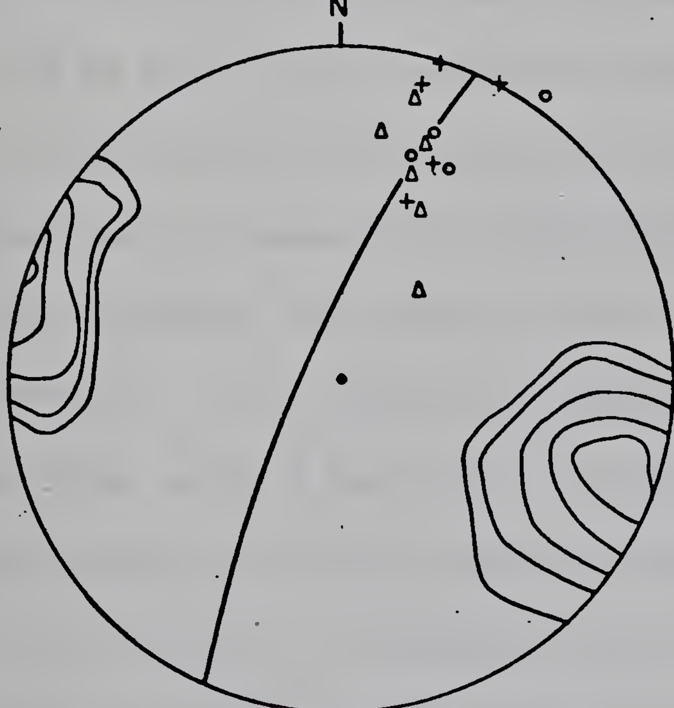
Linear features in the rocks of the eastern fold belt have been divided into two broad categories, one consisting of elongate mineral grains and stretched pebbles, and the other of axes of minor folds. Linear elements in rocks belonging to the migmatite-augen gneiss complex (map-unit 11) are not considered in the following discussion, as it was found they showed a very wide scatter on the stereonet, probably due to flow which is not necessarily related to any large scale folds. In every case in which the longest axis of a stretched pebble could be measured, it was parallel to the regional foliation direction and plunged at less than 6° to either the northeast or southwest. The major axes of the pebbles are probably parallel to the major fold axes. They indicate a similar north-northeast azimuth to that suggested by the bedding, but slightly shallower plunges. Only three examples of each of rodding and mineral lineations were noted in the eastern fold belt. In two cases the rodding is parallel to the regional foliation trend, in one case plunging 12° north-northeast and in the other case horizontal. The third example of rodding, in the meta-arkose west of Duddridge Lake, Sandfly Lake Area (East Half), plunges 55° to the southwest. The three examples of mineral lineation lie within foliation planes of the general

FIGURE 11A



Stereographic projection of 103 poles to foliation (contoured at 1% - 2% 4% - 8% - 12 %), S- and Z- folds (∘) crenulations (▵) and minor synclines and anticlines (+), from the part of the Meyers Lake group which forms the core of the more westerly major syncline, in the eastern fold belt, between section AB and the Churchill River, Sandfly Lake Area (East Half). Projected from lower hemisphere.

FIGURE 11B



Stereographic projection of 97 poles to foliation (contoured at 1% - 2% - 4% 8% - 12%), S- and Z- folds (∘), crenulations (▵), and minor synclines and anticlines (+), from the part of the Meyers Lake group which forms the core of the more easterly major syncline, in the eastern fold belt, south of the Churchill River, Sandfly Lake Area (East Half). Projected from lower hemisphere.

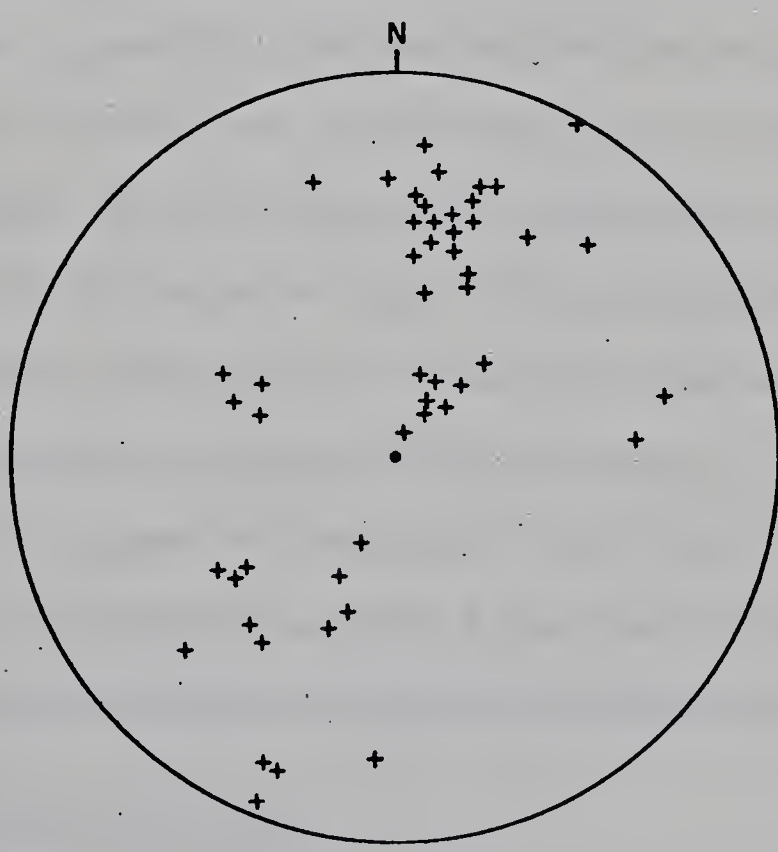
regional attitude and have plunges ranging from horizontal to 25° north. These few measurements provide little evidence concerning the nature of the folding.

When data on all types of minor folds (including crenulations, S- and Z-folds, and minor synclines and anticlines) from the eastern fold belt are plotted on a stereonet no one type shows a separate pattern, although the crenulations show a greater scatter than any other type (Figures 12A, 12B). The minor folds have been combined in a contour diagram (Figure 10B) because of this and because there are insufficient readings to treat each type statistically. This contour diagram has a maximum centred at about north 18° east, zero plunge and a second broad maximum centred at about north 16° east, plunge 40° north-northeast. The maxima occur in a broad, poorly defined girdle which has an attitude of about north 18° east and is approximately vertical. Any interpretation of this stereonet plot must be treated with caution because of the limited number of folds measured and the different types of folds included. Considering the size of the area covered and the limited data available, the positions of the girdle and the maximum at north 18° east, zero plunge are reasonably close to the positions of the average axial surface and of the average major fold axis respectively, as suggested by the orientation of bedding, metamorphic foliation, and stretched pebbles. The explanations for the girdle and second maximum present problems, however. If it is assumed that only one period of folding has occurred, then the girdle, which is due mainly to crenulations and S- and Z-folds, may be interpreted as being due to local irregular transverse wrinkling of beds. The "crumples" would lie in or nearly in the plane of the axial surface as they are developed in foliation planes which are parallel or nearly parallel to this surface. The second maximum, at north 16° east, plunge 40° north-northeast, is due predominantly to crenulations, although minor synclines and anticlines and S- and Z- folds also contribute to it. The position of this maximum may be fortuitous. Alternatively, it may be due to variations in the plunges of major fold axes. In any case, it seems

FIGURE 12A

Stereographic projection of axes of minor synclines and anticlines (+) and of S- and Z- folds (∘) in the metamorphic rocks of the eastern fold belt. Projected from lower hemisphere.

FIGURE 12B



Stereographic projection of axes of crenulations in the metamorphic rocks of the eastern fold belt. Projected from lower hemisphere.

likely that the plunges of major fold axes have a range of no greater than about 20° southwest to about 50° northeast, as this range includes most minor synclines and anticlines.

To summarize the discussion so far, the evidence discussed suggests that the predominant fold system in the eastern fold belt consists of isoclinal or nearly isoclinal, shallowly plunging, north-northeast trending folds with nearly vertical axial surfaces or planes. There is too little evidence to carry an analysis of the folding in the eastern fold belt much further, but the possibility of two or more periods of folding must be considered. The girdle of minor fold axes on Figure 10B may indicate development of a system of steeply dipping cross-warps, which is also suggested by the slight changes in strike of the traces of the axial surfaces of the fold system previously described. To check this possibility axes of minor folds were plotted on Figures 11A and 11B. The attitudes of minor folds on Figure 11B are reasonably consistent with those for the eastern fold belt as a whole. The minor folds shown on Figure 11A show a considerable scatter, however. There is a possibility that they may lie along two great circles, with orientations of about north 21° east, dip 76° northwest and north 22° west, dip 80° northeast, respectively. The first of these great circles closely coincides with the average axial surface of the folds shown on Figure 11B and is perpendicular to the maximum of the poles to foliation of Figure 11A. The second may be due to the development of cross-warps of somewhat variable north-westerly plunge. The outcrop pattern in this area (Figure 17) also suggests the presence of a cross-warp of this orientation. The available evidence is too limited to speculate further, but the presence of cross-warps (not necessarily unrelated to the major period of folding) seems to be possible.

MINOR BELTS AND WESTERN FOLD BELT

No evidence was observed as to the nature of fold structures in the minor belts of metamorphic and migmatitic rocks of the thesis area, with the exception of some near the eastern margin of the Black Bear Island Lake Area (West Half). The

nature of fold structures within the western fold belt in the thesis area is also unknown.

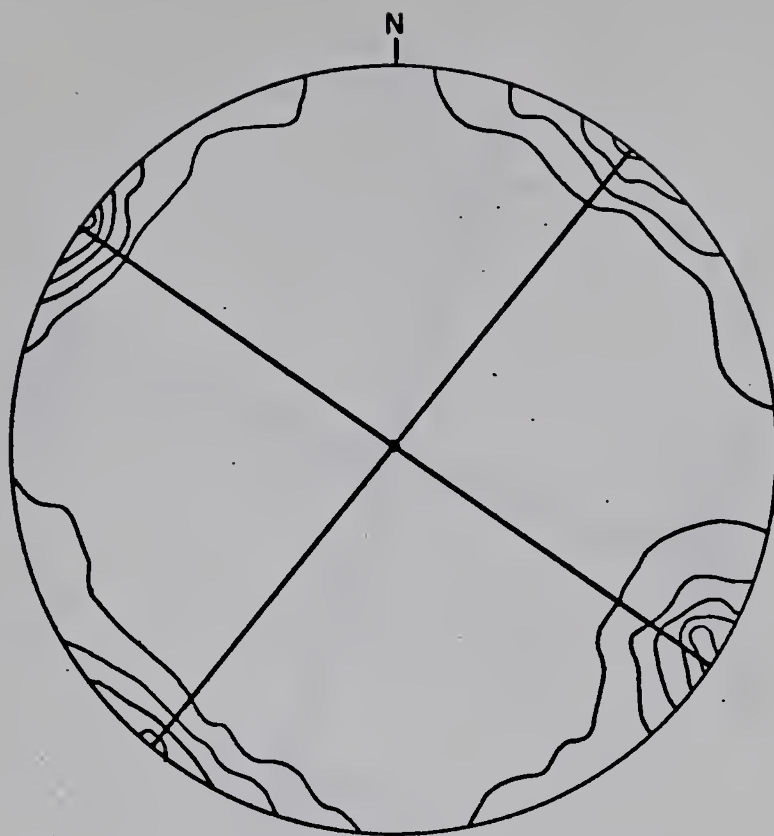
Mawdsley (1957, p. 32-34) stated that in the Middle Foster Lake Area, which is underlain by the western fold belt, the metamorphic rocks probably form a northeasterly trending and plunging anticline with an overturned eastern limb. The presence of a single major fold axis is postulated on the basis of the sequence of strata bordering a central intrusive belt. That this major axis is anticlinal is suggested by the presence of the central intrusions, as they would be less likely to occur along a synclinal axis. Diverse minor structures suggest the belt is a zone of crumpling and not a simple fold. Farther west, in the Daly Lake Area (East Half), the writer found (Money, in preparation) that the western fold belt consists of numerous north-easterly plunging synclines and anticlines whose axial planes are about one-half mile to two miles apart. In parts of the area the folding may be a little "tighter" and axial planes cannot be recognized.

The folds on and near Wamninuta Island, Black Bear Island Lake Area (West Half) are obscured in this area by extensive migmatization and granitic intrusion. Further east (Morris, personal communication) their axes appear to plunge to the southwest at angles in the range of 20° to 35°, based on the attitudes of gneissosity on the limbs and of minor folds. The anticline in the vicinity of Mac Dougal Bay, Besnard Lake, has a plunge of about 22° to the northeast.

Joints

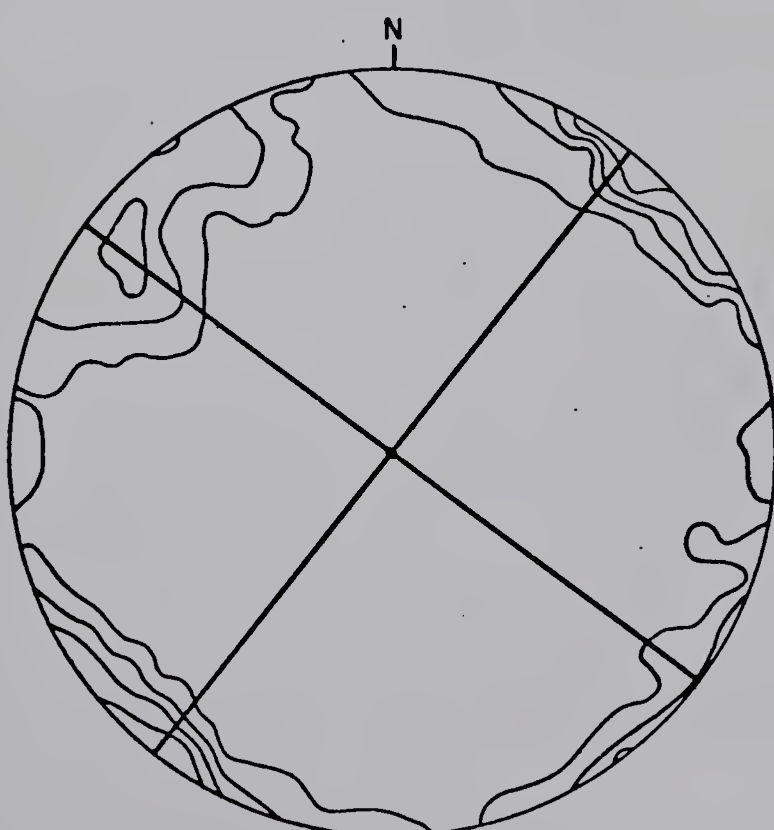
Poles of joints in the two main granitic masses and in the acidic meta-volcanic rocks were plotted on a stereonet (Figures 13A, 13B, 14). Horizontal joints have not been plotted. These are probably common in all rock types but are rarely seen as most outcrops do not have any vertical faces. The acidic meta-volcanic rocks were used because they are the only metamorphic rock in which joints parallel to foliation are not overwhelmingly predominant. In the western granitic rocks,

FIGURE 13A



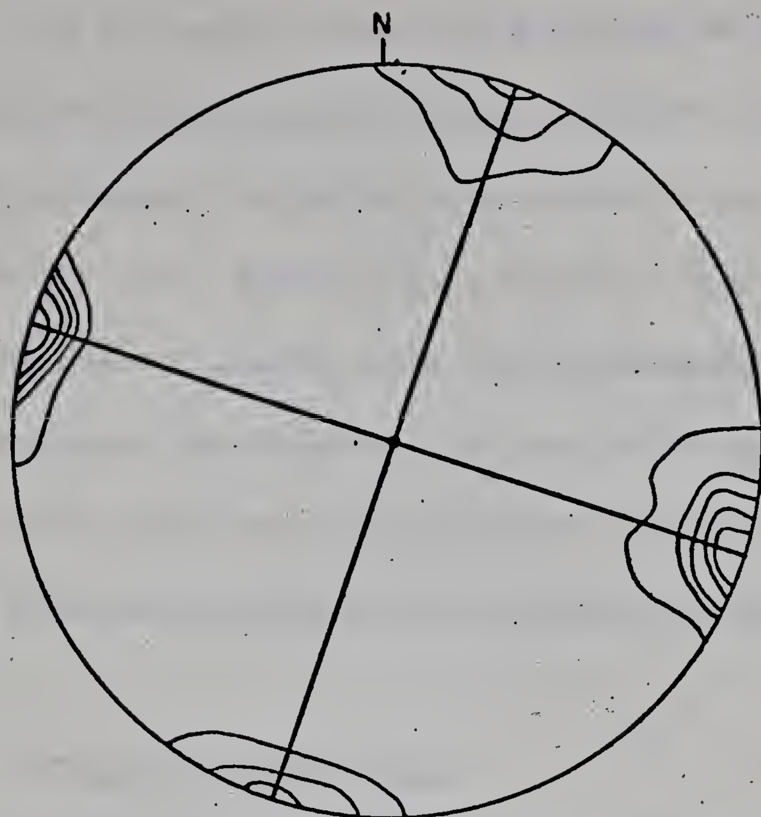
Stereographic projection of poles of joints (285) in the western granitic rocks. Contours 1% - 5% - 9% - 13% - 17%. Projected from lower hemisphere.

FIGURE 13B



Stereographic projection of poles of joints (239) in the eastern granitic rocks. Contours 1% - 3% - 5% - 7%. Projected from lower hemisphere.

FIGURE 14



Stereographic projection of poles of joints (56) in the acidic meta-volcanic (?) rocks. Contours 2% - 6% - 10% - 16% - 22%. Projected from lower hemisphere.

joint sets are at about north 51° west, vertical dip and north 34° east, dip 85° northwest. In the eastern granitic rocks they are at about north 54° west, vertical dip and north 34° east, dip 80° southeast. The acidic meta-volcanic rocks have sets at about north 20° east and north 69° west. Both sets dip vertically. In all three rock types, one joint set is nearly parallel to, and the other nearly perpendicular to the regional attitudes of contacts, fold axes, and foliation. In view of the regional nature of the jointing, and its similarity in older and younger granitic rocks and metamorphic rocks, it is suggested that the joints are probably tensional (release) fractures.

Faults and Shear Zones

Definite proof for the existence of faults and shear zones was found in the Eulas Lake Area (West Half) but not in the other two areas mapped. However, most or all of the lineaments indicated on the maps (Figures 16 and 17) accompanying this thesis probably are due to faulting and shearing.

The faults and shear zones may be divided into two sets: longitudinal faults and shears which trend north 20° to 70° east; and transverse faults which trend north 5° east to north 45° west.

The most conspicuous transverse fault is the Darnell Lake - Meyers Lake fault that is traceable for about ten miles north-northwest from Meyers Lake. This fault for most of its length occupies a muskeg-floored valley as much as several hundred feet wide. The valley walls are steep and rise to as much as 150 feet above the floor. Local vertical shearing was noted on these walls at the southern end of Darnell Lake, the northwest and southeast corners of Boxall Lake and the southeast bay of Meyers Lake. Vertically plunging slickensides are present at the southeast corner of Boxall Lake. A similar fault, along which shearing can also be seen locally, extends south-southeast from Chalk Lake and splits into two branches to the southeast. Vertically plunging slickensides were noted along the more westerly

branch. No evidence for the direction or amount of movement on the transverse faults was noted except for the slickensides. These imply essentially vertical movement, which is also suggested by the lack of apparent displacement of rock types across those faults.

The longitudinal faults and shears are characterized in some cases by scarps or narrow, steep-sided valleys along which shearing may be seen locally, and, in some cases, by development of a rusty gossan zone and a crumbly, highly weathered, quartz-sericite rock. No evidence of the direction and amount of movement along these faults and shear zones was found. The fault planes are vertical or steeply dipping. Frarey (1950, p. 7) reports a "strong shear zone" along the east edge of the giant quartz vein (map-unit 15) west of Sandfly Lake. If this exists, it belongs to the longitudinal set. This area was examined closely during the course of the present work. A biotite schist is present locally near the east edge of the quartz vein, but as its foliation is parallel to regional trends and no gossan or evidence of sericitization was noted, this cannot be considered as evidence for the presence of a shear zone. However, such a shear zone and many similar shear zones may be present, as due to the schistose nature of some of the country rock longitudinal faults and shears which lack obvious alteration are almost impossible to detect.

Only a few minor faults were noted in the map-area. Most of these belong to the longitudinal set but some belong to the transverse set. As reported in Chapters II and III, granulation is of widespread occurrence in both metamorphic and intrusive rocks. This granulation does not have any obvious relationship to the known faults and shear zones. It is particularly common in leucocratic quartzo-feldspathic rocks.

Chapter VIII

STRATIGRAPHY

On the basis of the radiometric dating and geological evidence, as discussed in Chapter VI, the rocks of the thesis area may be divided into three main groups. These are: (1) the western granitic rocks, probably emplaced ~2,300 m.y. ago or earlier; (2) the metamorphosed sedimentary, volcanic and plutonic rocks, probably mainly if not wholly younger than the western granitic rocks; and (3) the probably Hudsonian hornblende quartz diorite, eastern granitic rocks, pegmatite, and vein quartz.

The only metamorphic rocks which may be older than the western granitic rocks are the amphibolite, hornblende-biotite gneiss, biotite gneiss and schist, and pyroxene amphibolite which occur as small remnants within the granitic rocks outside of the eastern and western fold belts. These rocks are unsuited for Rb:Sr dating (see Chapter VI) and intrusive relationships cannot be used for dating because of the possibility of remobilization.

The metamorphic rocks which are probably younger than the western granitic rocks have been divided into three groups, the Meyers Lake Group, the "older metamorphic rocks", and the "cordierite-garnet rocks". The Meyers Lake Group (map-units 7, 8, and 9) is confined to the eastern fold belt. The "older metamorphic rocks" are defined as the metamorphic rocks (map-units 1 and 4 and part of 2 and 3) within the eastern fold belt which do not belong to the Meyers Lake Group. Rocks similar to certain of the "older metamorphic rocks" (amphibolite, hornblende-biotite gneiss, biotite gneiss and schist) which occur outside of the "eastern fold belt" cannot definitely be correlated with the rocks within the belt. These comprise most of the rocks which may be older than the western granitic rocks.

Within the eastern fold belt, the available evidence indicates that the Meyers Lake Group overlies the "older metamorphic rocks", probably unconformably.

The evidence for the Meyers Lake Group overlying the "older metamorphic rocks" is two-fold. Cross-bedding, preserved in the least deformed outcrop of the quartzite (map-unit 8) which forms part of the Meyers Lake Group, indicates that "tops" are away from the quartz-pebble meta-conglomerate (map-unit 7). This indicates that the meta-conglomerate is a basal conglomerate, rather than occurring at the top of the Meyers Lake Group. This is reasonable geologically; a thin but areally extensive basal conglomerate is a common feature of many sandstone sequences, whereas a similar unit at the top of such a sequence is more unusual. In the only nose of a fold which is well exposed (more easterly major syncline, about one mile west of Webb Lake, Sandfly Lake Area) numerous minor folds uniformly plunge north-northeast (Figure 17), indicating that this is truly a syncline and that the Meyers Lake Group (in the core of the fold) is younger than the surrounding "older metamorphic rocks". Minor folds in the noses of other folds support this evidence. In view of this evidence and the lack of any opposing evidence the writer accepts the younger age of the Meyers Lake Group. The evidence for an unconformity is as follows: (1) a basal meta-conglomerate is the lowest unit of most (although not all) of the Meyers Lake Group; (2) the Meyers Lake Group probably overlies in different places (Figures 16, 17) hornblende-biotite rocks and amphibolite, knobby biotite-plagioclase gneiss, biotite gneiss and schist, and meta-arkose, suggesting that an angular unconformity is present; and (3) the Meyers Lake Group was probably deposited in shallow seas under conditions of slow subsidence whereas the "older metamorphic rocks" are indicative of rapid subsidence (see Chapter IV).

The relationship of the cordierite-bearing schists and associated rocks (the "cordierite-garnet rocks") to the Meyers Lake Group and the "older metamorphic rocks" is not known, as these were nowhere seen in contact. The following facts are pertinent to this problem:

1. The "cordierite-garnet rocks", within the thesis area, consist of metamorphosed arkosic arenites, biotitic rocks which are probably true pelites, and minor calc-silicate rocks. In the Daly Lake Area, East Half, (Money, in preparation) there are also minor hornblende-biotite rocks, amphibolite, and arkosic meta-conglomerate, and various biotitic gneisses. In the Middle Foster Lake area (Froese, 1956) the seqquence is reported to also probably contain greywacke and spilites, but the writer does not consider this contention to necessarily be valid (see Chapter IV).

2. In the thesis area, rocks belonging to the "cordierite-garnet rocks" outcrop both east and west of the eastern fold belt. The rocks to the east include biotite-cordierite-garnet gneiss, migmatites derived from these rocks, and calc-silicate rocks. Correlation of the eastern and western rocks is not certain, but is most probable in view of the similar lithology. The "cordierite-garnet rocks" to the east are areally associated with amphibolite, hornblende-biotite rocks, and biotitic rocks which have been grouped into map units (2), (11c), and (11e). These may be correlative with lithologically similar rocks within the eastern fold belt which are part of the "older metamorphic rocks".

3. McMurchy (1938b) shows a connecting link between the eastern fold belt (Meyers Lake Group, "older metamorphic rocks") and the western fold belt ("cordierite-garnet rocks") on the Foster Lake Sheet, West Half (see Figure 15). The writer (Money, 1961) investigated the junction of the link and the eastern fold belt in the Barnett Lake Area (West Half). Here the link is composed of biotite schist and gneiss, in part garnetiferous. The garnetiferous rocks are confined to the link and the west side of the eastern fold belt, although biotitic rocks are interlayered with the biotite-hornblende rocks and amphibolite in other parts of the eastern fold belt. The garnetiferous rocks contain appreciable plagioclase and lack cordierite; sillimanite is rare. Structurally, they appear to overlie the biotite-hornblende rocks and amphibolite.

The "cordierite-garnet rocks" and the Meyers Lake Group do not have a single rock type in common and were probably formed in very different depositional environments (see Chapter IV). It is considered unlikely that the two groups are correlative. Rock types in the "cordierite-garnet rocks" and the "older metamorphic rocks" with some mineralogical similarity include the meta-arkose, arkosic meta-conglomerate, and perhaps the biotitic rocks, hornblende-biotite rocks and amphibolite. The meta-arkose and associated pebbly meta-arkose and arkosic meta-conglomerate in the two groups are not particularly similar. In the "cordierite-garnet rocks" these rock types are either calcareous or biotitic, in the "older metamorphic rocks" they are muscovitic. The conglomeritic parts are also different; the meta-conglomerate of the "cordierite-garnet rocks" contains pebbles, cobbles, and boulders of a greater variety of rock types (see Correlation with the "older metamorphic rocks", Chapter

IX) that the pebbly meta-arkose belonging to the "older metamorphic rocks". The hornblende-biotite rocks of the "cordierite-garnet rocks" are very minor in extent. In view of their uncertain origin (Money, in preparation) they are of little value in correlation. The biotitic rocks of the "cordierite-garnet rocks" are probably partly meta-greywacke but are mainly metamorphosed true pelites (Money, in preparation) whereas the biotitic rocks belonging to the "older metamorphic rocks" are wholly or predominantly meta-greywacke.

From the preceding discussion, it is obvious that the "cordierite-garnet rocks" differ considerably from the "older metamorphic rocks" in lithology. If the "cordierite-garnet rocks" are equivalent to them in age there must be a (sedimentary) facies change. The presence of rocks belonging to the "cordierite-garnet rocks" both east and west of the eastern fold belt in the thesis area (see Figures 16, 17) implies that if there was one facies change there must have been at least two facies changes, that is, "cordierite-garnet rocks" to "older metamorphic rocks" to "cordierite-garnet rocks". The present distance over which these two changes would have occurred is about 12 miles; it may have originally been much greater. The facies boundary would have to be parallel to or nearly parallel to the present fold axes, or a gradation along strike in the eastern fold belt to "cordierite-garnet rocks" or in the western fold belt to the "older metamorphic rocks" would be expected to occur. The only evidence for such a gradation is provided by the garnetiferous biotitic rocks of the Barnett Lake Area (West Half). These rocks may be transitional between those forming the "cordierite-garnet rocks" and the "older metamorphic rocks". There is no proof that they are truly correlative with the "cordierite-garnet rocks" and even if they are they may overlie the "older metamorphic rocks", perhaps unconformably. The writer thinks that although a facies change is a possible explanation for the relationship of the "cordierite-garnet rocks" and the "older metamorphic rocks" the evidence is very inconclusive and the two groups may well be of different age.

If so, the evidence of the Barnett Lake Area suggests that the "cordierite-garnet rocks" could be younger than the "older metamorphic rocks".

The rocks not as yet discussed which occur in the thesis area are all intrusive. The oldest is presumably the epidiorite which intrudes the "older metamorphic rocks" and probably intrudes the Meyers Lake Group (see "Epidiorite", Chapter II). Hornblende quartz diorite, which occurs only as inclusions in the eastern granitic rocks, is probably next in age, followed by the eastern granitic rocks, pegmatite, and vein quartz (see Chapters III and VI). The pegmatite is probably not all of the same age as it is probably not all of the same origin, and some of it could be older than the eastern granitic rocks or younger than the vein quartz.

Chapter IX

REGIONAL CORRELATION AND NOMENCLATURE

Introduction

It is difficult at present to make a reliable correlation of the rocks of the thesis area with rocks in other parts of northern Saskatchewan or elsewhere. This is partly due to the limited mapping and radiometric dating which have been carried out. It is also partly due to geological factors, such as the occurrence of the metamorphic rocks as remnants surrounded by granitic rocks, the isoclinal or nearly isoclinal nature of much of the folding, the general lack of marker horizons, and the high grade of metamorphism. Because of this difficulty correlation will be attempted only with the rocks on strike with those of the thesis area.

Correlation

INTRODUCTION

The metamorphic rocks of the thesis area form part of two major north-north-east to northeast trending fold belts (Figure 15). The more easterly belt is the "eastern fold belt" of the thesis area. The rocks belonging to the "cordierite-garnet rocks" which occur near the western edge of the map area are the eastern fringe of the western fold belt. The southernmost exposed part of the western belt, in the Ile-a-la-Crosse area, is represented by the areas of Frarey's (1950) unit (3b) which occur between Snake Lake and Sandfly Lake. These extend from the edge of the exposed shield to the northeast corner of the Ile-a-la-Crosse area. This part of the fold belt is much broken by granitic rocks. Further north, as shown on the Foster Lake Sheet, West Half, (McMurchy, 1938b), the western fold belt occurs west of the Foster River and Lower Foster Lake. It and the eastern fold belt appear to coalesce at about 105°05'W and 56°44'N. It is uncertain how much the western fold belt is broken by areas of granitic rocks, as McMurchy could

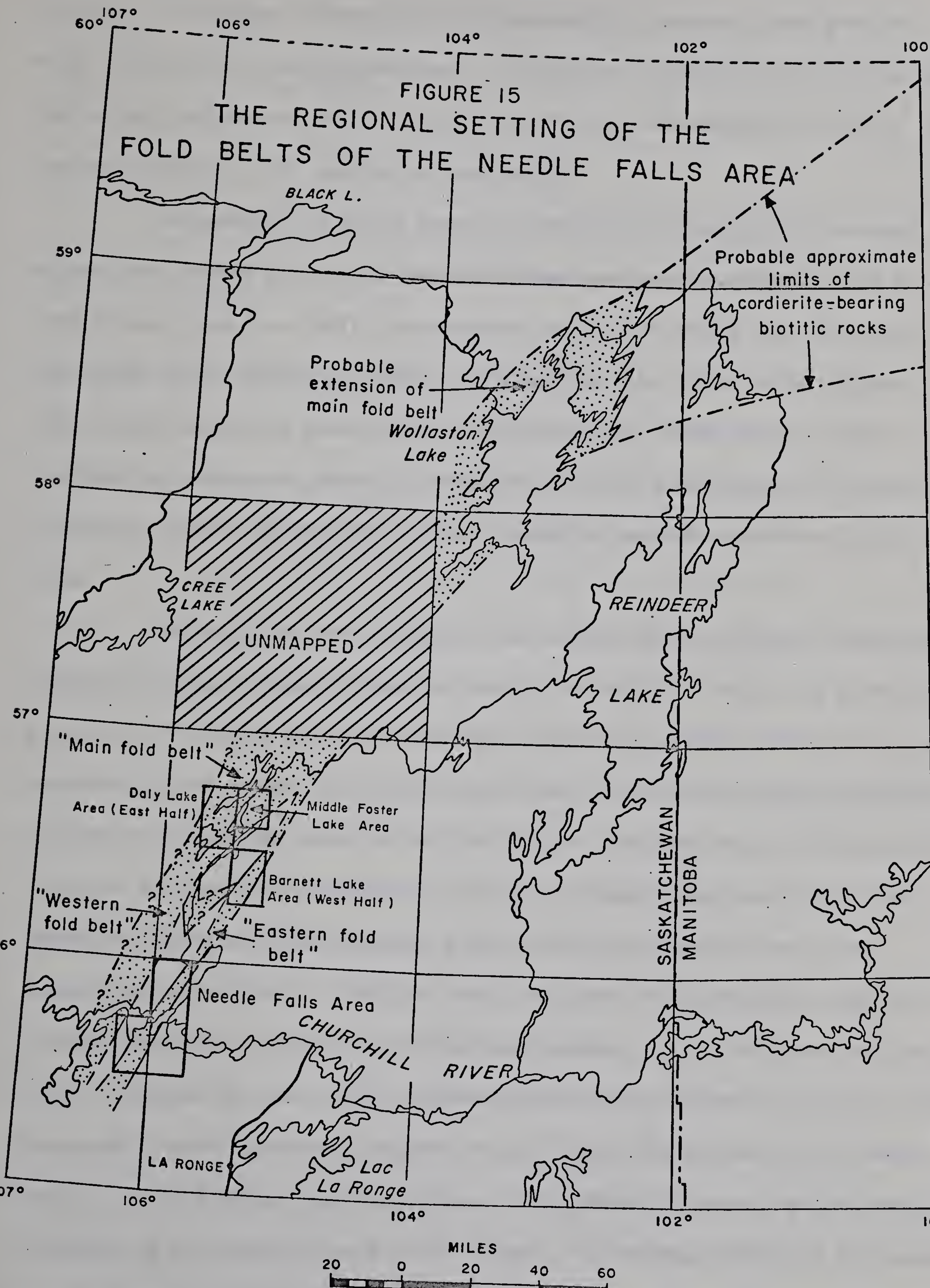


FIGURE 15
THE REGIONAL SETTING OF THE
FOLD BELTS OF THE NEEDLE FALLS AREA
60°
107°
106°
104°
102°
100°
60°
59°
58°
57°
56°
55°
BLACK L.
Probable approximate limits of cordierite-bearing biotitic rocks
Probable extension of main fold belt
Wollaston Lake
CREE LAKE
UNMAPPED
REINDEER
LAKE
"Main fold belt"
Daly Lake Area (East Half)
Middle Foster Lake Area
Barnett Lake Area (West Half)
"Western fold belt"
"Eastern fold belt"
Needle Falls Area
CHURCHILL RIVER
SASKATCHEWAN
MANITOBA
LA RONGE
Lac La Ronge
MILES
20
0
20
40
60

not make a satisfactory differentiation of metamorphic, migmatitic and granitic rocks on the scale of mapping employed. A possible connecting link occurs between the westerly and easterly belts in the vicinity of and southwest of Barnett Lake. This has been discussed in the section on stratigraphy.

The eastern fold belt is known to extend from the edge of the exposed shield, near Besnard Lake in the Ile-a-la-Crosse area, north-northeast across the Sandfly Lake Area (East Half), the northwest corner of the Black Bear Island Lake Area (West Half), (McLarty, 1936a); the Eulas Lake Area (West Half), (McLarty, 1936a); and Foster Lake Sheet (West Half),(McMurchy, 1938b; Money, 1961). This fold belt, although generally less than 4 to 6 miles wide, appears to be more continuous than the western belt, which is probably generally more than 10 miles wide.

The single fold belt formed by the two belts north of the point where they coalesce continues to the northeast and may be as much as 20 miles wide at the north boundary (57°00'N) of the Foster Lake Sheet (McMurchy; 1938a, 1938b). The area immediately north of this, the Geikie River sheet, has not been mapped geologically. However, the topographic map of the Geikie River area (Department of Mines and Technical Surveys, 1963) indicates no change in structural trend and the fold belt apparently continues its northeasterly trend across the northwest corner of the Spalding Lake area (Weeks, 1940) and across the centre of the Wollaston Lake area (Fahrig, 1958) to the Saskatchewan-Manitoba boundary. In the Whiskey Jack Lake area of Manitoba (Currie, 1961), immediately east of the Wollaston Lake area, the metamorphic rocks have a more easterly trend. They strike due east near its eastern margin. In the Kasmere Lake area (Fraser, 1962), which is north of the Whiskey Jack Lake area, a more easterly trend is also evident, but northeast strikes are still common near this area's boundary. On both of these maps the metamorphic rocks are shown as more or less discontinuous lenses and patches within the predominant granitic

rocks and migmatite and a single fold belt does not really exist. The "main fold belt" is shown, therefore, as ending within the Wollaston Lake Area on the accompanying map (Figure 15). Further east in the Tadoule Lake (Davison, 1962), Munroe Lake (Davison, 1963) and Shethanei Lake (Taylor, 1958) areas, the various metamorphic rocks occur in fairly broad, open folds which are not traceable for any great distance. The traces of the axial surfaces of most of these folds range in azimuth from southeast to northeast.

CORRELATION WITH THE MEYERS LAKE GROUP

Within the fold belt (and the fold belts in the southern part) rocks resembling the Meyers Lake Group are of fairly restricted occurrence. The writer (Money, 1961, p. 12) has reported minor pure quartzite, interlayered with meta-arkose, from the Barnett Lake Area (West Half). This was only noted in six places and the largest bed seen is only 100 feet thick. The only accessory mineral(s) are magnetite and/or ilmenite and minor minerals are biotite, plagioclase (oligoclase-andesine?) and microcline. These quartzites differ markedly in occurrence, accessory mineral content, minor mineral content and areal extent from the quartzite of the Meyers Lake Group and cprrelation is most unlikely; in fact, after examining the vein quartz of the Sandfly Lake Area (East Half), the writer thinks that the "quartzite" of the Barnett Lake Area (West Half) also may be vein quartz.

An occurrence of rocks similar to the Meyers Lake Group is found about 180 miles to the northeast of it, in the Wollaston Lake area, where they form part of Fahrig's (1958) unit 1. The pertinent part of his description follows:

> "Thin pebbly conglomerate layers consisting of white quartzite pebbles in a biotitic matrix occur on several islands in Wollaston Lake. The conglomerate generally is interbedded with rusty weathering meta-quartzite. Light to dark green lime-silicate and carbonate-lime-silicate layers are common and typically associated with quartzite."

Fahring (1958) also suggested that the basin of Wollaston Lake may form a major structural low. In response to a letter from the writer he stated (1963) that:

"Your idea of an unconformity within this region of gneiss is an interesting one but I can't comment intelligently on the possibility of applying it to the Wollaston area. However, I have suggested that the basin of the Lake is a synform so that the lime-silicate-quartzite sequence may overlie neighbouring gneisses.....Map unit (1) in the Phelps Lake area may well correlate with unit (1) in the Wollaston Lake."

He also (1963, personal communication) enclosed somewhat more detailed notes than those which appeared in 1958. These notes mention the occurrence in the quartz-rich meta-sedimentary rocks of white weathering ovoid inclusions, now consisting mainly of sillimanite, which may have been intraformational shale pebbles.

If one allows for an increase in carbonate content to the northeast, these rock types could be equivalent to the Meyers Lake Group. The rocks underlying (?) them appear to belong to the "cordierite-garnet rocks" rather than to the "older metamorphic rocks", but if there is an unconformity at the base of the Meyers Lake Group this is reasonable. However, the writer does not feel that a definite correlation is justified at present.

The Phelps Lake area, immediately north of the Wollaston Lake area, was mapped by Tremblay (1960). His map unit (1), which occurs north and west of the writer's "main fold belt", consists of argillite, greywacke, impure quartzite and minor white quartzite. A sub-unit, (1a), consists of fine to coarse crystalline limestone and dolomite. This unit occurs near the eastern boundary in the Phelps Lake area and extends into the adjacent Kasmere Lake area (Fraser, 1962). Tremblay's unit (1) is Fraser's unit (2), which he subdivides into (2a), metamorphosed argillite and siltstone; and (2b), biotite quartzite and metamorphosed greywacke. The carbonate rocks, Tremblay's sub-unit (1a), are equivalent to Fraser's unit (3), described as consisting of dolomite with minor crystalline limestone and skarn rocks. The carbonate-quartzite sequence, as described by Tremblay and Fraser, differs greatly from the Meyers Lake Group. It could be equivalent to the Meyers Lake Group only if there is a major facies change from orthoquartzite and feldspathic sandstone to the south-southwest (the Meyers Lake Group) to predominantly impure quartzite

(greywacke), argillite, limestone and dolomite to the north-northeast. This is possible, as the Wollaston Lake area quartzitic rocks appear to be intermediate in character, but considering the present state of knowledge such a correlation is at best highly speculative. In the Whiskey Jack Lake area there is a pure, white glassy quartzite, sub-unit (4a) which Currie (1961) stated "does not seem to be associated with the other metamorphic rocks." Quartzites are also reported further east in the Tadoule Lake area (Davison, 1962) and the Munroe Lake area (Davison, 1963), associated with calcareous and arenaceous rocks. Davison reported that in the Tadoule Lake area these rocks are dark coloured and unmetamorphosed to slightly metamorphosed. They include quartz pebble conglomerate, in several exposures grading into greywacke, and a breccia conglomerate near the eastern margin of the area which

> "contains assorted angular and rounded fragments of gneiss, quartzite, micaceous sandstone, and other rocks, together with quartz pebbles, in a silty to gritty matrix."

In the Munroe Lake area part of the quartzitic sequence is similar to that of the Tadoule Lake area but part, sub-unit (3a), consists of pale, indistinctly bedded and strongly jointed quartzite which has feldspathic, garnetiferous and biotite-bearing varieties locally. Davison (1963) suggested that sub-unit (3a) could represent a distinctly older series. He suggested that in both map areas the quartzitic rocks overlie various granitoid and other rocks. In the Tadoule Lake area these underlying rocks were described as consisting of granular quartz-feldspar gneiss, hornblende-quartz gneiss, and intimately associated granular granite, with minor amphibolite. In the Munroe Lake area they were described as consisting of buff to pinkish-brown granulite, granite gneiss, and gneissic granite, with minor amounts of amphibolite and meta-sedimentary gneiss. The typical granulite of the latter area contains small amounts of hypersthene. In both map areas the quartzitic rocks are intruded by younger granitic rocks.

CORRELATION WITH THE"OLDER METAMORPHIC ROCKS"

The "older metamorphic rocks" can also be traced northeast from the thesis area. A very similar sequence, including hornblende-biotite rocks and meta-arkose, occurs in the Barnett Lake Area (West Half) (Money, 1961). In the Middle Foster Lake Area, which is underlain mainly by rocks belonging to the "cordierite-garnet rocks", Mawdsley (1957, p. 15) reports an outcrop which may be conglomerate immediately west of the main granodiorite mass of the area. This outcrop is much altered and perhaps granitized. Mawdsley notes that here some of the fragments,

> "look like pebbles of fine-grained granite, others are almost white and fine sugary-looking and resemble...feldspathized fragmentals...Within six inches of some of these light coloured fragments the rock passes into a typical grey biotite granulite."

This outcrop could possibly be equivalent to the pebbly meta-arkose (part of the "older metamorphic rocks") of the writer's thesis area. In the Daly Lake Area (East Half) (Money, in preparation), a meta-conglomerate on strike with that described by Mawdsley occurs as part of a sequence of meta-arkose. In places it contains numerous granitoid pebbles, cobbles and boulders, but in other places quartz pebbles and cobbles are predominant. A few dioritic or gabbroic cobbles (?) were also noted. This meta-conglomerate and the related meta-arkose are part of a sequence consisting of calc-silicate rocks, cordierite-biotite rocks, cordierite-biotite-garnet rocks, biotite rocks, and minor hornblende-biotite rocks and amphibolite. This sequence apparently belongs to the "cordierite-garnet rocks". The meta-arkose is biotitic or calcareous (actinolitic), unlike the muscovitic meta-arkose of the thesis area, and none of the associated rocks resemble those forming the "older metamorphic rocks" of the thesis area. The writer feels that correlation of the two types of meta-arkose is not justified at present.

Hornblendic rocks, possibly of igneous origin, occur near the southeast corner of the Wollaston Lake area (Fahrig, 1958) east of the main fold belt. Fahrig

also reported a conglomerate near the southwest corner of the area which consists of thin lensoid granitic and darker boulders in a medium-grained pink to grey schistose matrix, and metamorphosed arkose (undescribed) is listed in his legend as part of map unit (1). Correlation of any of these rocks with the "older metamorphic rocks" is extremely speculative in view of their limited extent and lack of continuity and the the common occurrence of such rocks throughout the Precambrian of Saskatchewan and adjacent areas. Feldspathic sandstones or meta-arkoses have also been reported in the Kasmere Lake (Fraser, 1962) and Whiskey Jack Lake (Currie, 1961) areas. They are fairly extensive in the former area. Minor amounts of hornblende-bearing rocks occur in these areas and the areas further east.

CORRELATION WITH THE "CORDIERITE-GARNET ROCKS"

Rocks belonging to the "cordierite-garnet rocks" are widespread within the main fold belt, and to the south, its more westerly branch, and quite scarce elsewhere. They have been reported, from southwest to northeast along strike, in the Ile-a-la-Crosse Area (Frarey, 1950); the Daly Lake Area (East Half),(Money, in preparation); the Middle Foster Lake Area (Mawdsley, 1957); the Wollaston Lake Area (Fahrig, 1958); the Whiskey Jack Lake area (Currie, 1961) and the Kasmere Lake area (Fraser, 1962). In all cases the group includes non-cordieritic and non-garnetiferous biotitic rocks. Calc-silicate rocks and calcareous meta-arkose (Money, in preparation) also form part of the group.

The "cordierite-garnet rocks" are probably fairly continuous from the Ile-a-la-Crosse area to the northeast corner of the Wollaston Lake area and probably can be correlated, as a group, within this region. The writer thinks that the cordieritic rocks farther east (in Manitoba) perhaps also should be correlated with the "cordierite-garnet rocks" but they are less abundant and the absence of a clearly defined fold belt presents a problem in correlation.

Nomenclature

McLarty (1936a, 1936b) correlated the metamorphic rocks of the Eulas Lake Area (West Half) and the Black Bear Island Lake Area (West Half), as well as the metamorphic rocks northeast of La Ronge, with the Wekusko Group. This correlation must be rejected on the grounds that the type Wekusko Group occurs nearly 200 miles away across strike, its age relationship to the rocks of the thesis area is unknown, and McLarty gave no reasons for his correlation. No other names had been proposed for the metamorphic rocks of the thesis area before mapping by the writer commenced. The term Meyers Lake Group, for the quartz-pebble meta-conglomerate and overlying rocks which occur in the eastern fold belt of the thesis area, is considered justified because of the distinctive lithology of this group (Chapter II) and the probable presence of an unconformity beneath it(Chapter VIII). The "older metamorphic rocks" and the "cordierite-garnet rocks" have been left unnamed because they have some similarity to the metamorphic rocks northeast of La Ronge but correlation is not certain, and because the nomenclature for the metamorphic rocks north of La Range is itself in a state of confusion. McInnes (1909) named the meta-sedimentary and meta-volcanic rocks north of La Ronge the Lac La Ronge series. Mawdsley and Grout (1951) proposed that these rocks be re-named the La Ronge Group. However, they applied the term La Ronge Group, nowhere adequately defined, to a meta-sedimentary sequence (biotite schists, calc-silicate rocks, limestones) which occurs northeast of La Ronge, and <u>not</u> to the meta-volcanic and meta-arkose sequence which is typical of the La Ronge meta-volcanic belt. It is obvious that a re-definition of terms is required, but the writer feels that to introduce new ones at this time would only compound the confusion.

Chapter X

SUMMARY AND CONCLUSIONS

RADIOMETRIC DATING

The igneous and metamorphic rocks within the thesis area which were dated all had been formed by the end of the Hudsonian orogeny. The last phases of this orogeny within this area probably occurred ~1750 million years ago, based on K-Ar dates on micas. Rb-Sr dating shows that one major unit, the western granitic rocks, probably formed at least ~ 2300 million years ago, and perhaps as much as ~ 2500 million years ago. Two hornblende K-Ar dates of ~1,870 million years may be a result of partial up-dating of older rocks or may due to trapping of excess argon by the hornblende. An "anomalous" biotite K-Ar date of ~1,560 million years is believed to be due to partial up-dating caused by movement along a fault or by the effects of solutions which travelled along the fault.

INTRUSIVE ROCKS

The major granitic unit in the thesis area, apart from the ~ 2300 million year old western granitic rocks, is the eastern granitic rocks. The eastern granitic rocks have a minimum age of ~ 1,690 million years and a possible maximum age of ~1,870 million years. The presence of only local granulation in the eastern granitic rocks in contrast to the widespread granulation in the western granitic rocks, suggests that the former are related to the Hudsonian and not to an earlier orogeny. They are probably intrusive into and younger than all of the metamorphic rocks. Minor intrusive rocks include hornblende quartz diorite (which has been found only as inclusions in the eastern granitic rocks), pegmatite, and giant quartz veins. Hornblende from the quartz diorite gives a K-Ar age of ~1,870 million years. The significance of this is uncertain. The pegmatite is probably, but not necessarily, all younger than the eastern granitic rocks; several varieties of probably diverse

origins occur. The quartz veins appear to be the youngest consolidated rocks of the area, although some of the pegmatites and even possibly the eastern granitic rocks could conceivably be younger.

Both the western and eastern granitic rocks are fairly homogeneous, occupy large areas, contain rotated inclusions, and lack ghost stratigraphy. Samples from both plot near the minimum on "petrogeny's residua system" (Tuttle and Bowen, 1958) and an igneous origin, rather than a metasomatic one, is implied. The composition of the western granitic rocks appears to have been slightly modified, probably during the Hudsonian orogeny, and hence estimates of temperature and water vapour pressure at the time of formation are probably not valid. The single analysed sample of the eastern granitic rocks with ab+or+Q greater than 80 suggests a P_{H_2O} of about 2000 kg/cm^2 and a temperature of about 700° to 740°C at time of formation.

Pegmatites include large intrusive, igneous bodies with chilled margins, small pods of segregation pegmatite with the same mineralogy as the host rocks, and numerous bodies which could be either igneous or formed by metamorphic segregation. The vein quartz has definite intrusive characteristics. Its origin is uncertain, but it may be related either to the quartzite (unit 8) or to the western granitic rocks.

METAMORPHIC ROCKS

On geological grounds all major groups of metamorphic rocks are considered younger than the western granitic rocks. If Rb-Sr whole rock dates for the metamorphic rocks represent the age of sedimentation and volcanic activity they formed immediately prior to the last phases of the Hudsonian orogeny. However, the Rb-Sr dates are probably due to metasomatism related to the Hudsonian orogeny and hence the exact age of the metamorphic rocks is uncertain.

The metamorphic rocks belong, for the most part, to the amphibolite

facies, andalusite-sillimanite type (Miyashiro, 1961). Rocks belonging to the lower temperature mineral zone B definitely occur in the eastern fold belt and may occur outside of it. Most of the metamorphic rocks outside of the eastern fold belt definitely or probably belong to mineral zone C, and some of the rocks within this fold belt also probably belong to this zone. An assemblage belonging to the hornblende granulite subfacies is confined to inclusions in granitic rocks and does not represent normal conditions of metamorphism in the area. The metamorphic rocks of zone C have a fairly reliable minimum temperature of formation of about 520°C, and a possible maximum temperature of between perhaps 760°C and 860°C. Maximum and minimum pressures of formation are in the order of 8 and 4.4 kilobars, assuming that $P_{H_2O} = P_{load}$. The evidence for the minimum pressure is of very dubious reliability. The maximum possible depth of burial is about 28 kilometers, assuming an average density of 2.8 gm/cm^3. A minimum geothermal gradient of 22°C/km has been calculated for the rocks of mineral zone C. The average modern value is close to 30°C/km. The agreement is considered good in view of many uncertainties in the data and the fact that the calculated gradient is a minimum one.

The original nature of most of the metamorphic rocks can be determined with varying degrees of certainty. The rock types and their most likely origins are tabulated below:

Meta-arkose	arkosic wacke
Hornblende-biotite rocks	intermediate volcanic rocks or tuff or greywacke derived from volcanic rocks
Amphibolite	in part basic volcanic rocks, in part uncertain
Hornblende-biotite-clinopyroxene rock	calcareous sediment
Biotite schist and gneiss	greywacke
Acidic meta-volcanic(?) rocks	rhyodacite, dacite, acidic tuff
Biotite-cordierite-sillimanite rocks	mainly pelite, minor interlayers of arkosic arenite
Plagioclase-scapolite-clinopyroxene rock	calcareous sediment

Hypersthene amphibolite	uncertain
Clinopyroxene amphibolite	calcareous sediment
Quartz pebble meta-conglomerate	oligomictic conglomerate
Quartzite	quartz arenite, feldspathic arenite, very minor arkosic wacke
Biotite-muscovite-quartz schist	pelite
Epidiorite	diorite

Meta-arkose, hornblende-biotite rocks, amphibolite, biotite schist and gneiss, and acidic meta-volcanic (?) rocks belong to the "older metamorphic rocks", which are probably unconformably overlain by quartz-pebble meta-conglomerate, quartzite, and biotite-muscovite-quartz schist, which collectively form the Meyers Lake Group. The biotite-cordierite-sillimanite rocks, hornblende-biotite-clinopyroxene rocks, and plagioclase-scapolite-clinopyroxene rocks belong to the "cordierite-garnet rocks". This group probably is not correlative with the Meyers Lake Group. Its relationship to the "older metamorphic rocks" is uncertain. Outside of the thesis area it contains abundant meta-arkose, some meta-greywacke or meta-subgreywacke and possibly minor meta-volcanic rocks. The pyroxene amphibolites are confined to small bodies within granitic rocks. Their stratigraphic position is uncertain. Epidiorite (unit 10) is intrusive into the "older metamorphic rocks" and probably into the Meyers Lake Group.

The "older metamorphic rocks" were probably deposited in an intracratonic basin or geosyncline with a sialic basement. The group has some resemblance to Pettijohn's (1957) greywacke suite but differs from this suite sufficiently that it is unlikely the group was deposited in a typical geosynclinal environment. The presence of abundant immature rocks (greywacke, arkosic wacke) implies rapid deposition in an essentially unstable crustal area.

The Meyers Lake Group has some resemblance to the orthoquartzite-carbonate suite, characteristic of stable cratons. However, it lacks carbonates and contains abundant although subordinate pelites and feldspathic arenites, unlike

the characteristic stable shelf deposits. It is inferred that the Meyers Lake Group was deposited during a period of relative stability in an essentially unstable crustal area on the basis of its stratigraphic position above the "older metamorphic rocks" and its involvement in the Hudsonian orogeny. The presence, at the base of the group, of metamorphosed conglomerate with interlayered pelites and quartzites and the occurrence of cross-bedding in the quartzites suggests shallow water marine deposition and a fluctuating shoreline.

The environment of formation of the "cordierite-garnet rocks" is difficult to evaluate because of very limited evidence. The most likely possibility is that it was deposited in a geosyncline or intracratonic basin with a sialic basement.

STRUCTURE

The metamorphic rocks of the eastern fold belt have been folded into isoclinal or nearly isoclinal, doubly plunging folds with nearly vertical limbs. The traces of axial surfaces of these folds trend north-northeast, parallel to the margins of the fold belt. Both axial plane and bedding plane foliation are probably present. Folding of similar style may occur in the western fold belt and in most of the smaller belts of migmatitic and metamorphic rocks. At the extreme eastern edge of the thesis area, in the Black Bear Island Lake Area (West Half), migmatites occur in somewhat more open folds that plunge to both the southwest and northeast.

Two types of faults occur, north-northwest trending transverse faults, and north-northeast trending longitudinal faults. Very limited evidence suggests vertical movement on both. Steeply dipping contacts show no apparent displacement on the major transverse fault so that horizontal movement on this must be minor.

Joints in the eastern granitic rocks, the metamorphic rocks, and the western granitic rocks have virtually the same pattern. It is inferred that they are a post-orogenic release feature. Two joint sets are common, one parallel and the other perpendicular to the regional attitude of foliation and contacts. Both dip

steeply to vertically.

REGIONAL CORRELATION

The "cordierite-garnet rocks" can be traced to the north-northeast as a distinctive fold belt, although much interrupted by granitic bodies, for some 300 miles. Smaller remnants of cordierite-bearing biotitic rocks occur on strike for at least 100 miles beyond this, for a total strike length of at least 400 miles. The "older metamorphic rocks" of the eastern fold belt are definitely traceable north-northeast to the Barnett Lake Area (West Half), a total strike length of about 75 miles, and may occur east of the "cordierite-garnet rocks" further to the north-northeast. No rocks which occur on strike with the Meyers Lake Group and are correlative with them are known, with the possible exception of some quartzites which occur on islands in Wollaston Lake. These occur about 180 miles north-northeast of the most northerly known occurrence of the Meyers Lake Group.

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APPENDIX I SAMPLING AND MODAL ANALYSIS

As stated in Chapter I, the nature of the mapping has imposed certain limitations on sample collection and selection. The main limitations are that the stratigraphic positions of samples used in subsequent work were generally not known at the time they were collected; and in most cases it was impossible to re-visit a given outcrop. It is scarcely possible, given this type of sampling, to relate minor lithological variations within a map-unit to its internal stratigraphy. However, gross lateral variations in mineralogical composition due to variation in metamorphic grade or chemical composition might be discerned.

During mapping hand specimens were collected at one half mile intervals, wherever possible, in apparently homogeneous rocks, and at much closer intervals in areas of changing or diverse lithology. Approximately 2,000 hand specimens were obtained and about 350 of these were selected for preparation of thin sections. In making this selection the hand specimens were first divided by rock type, and then wherever possible extreme variants and a number of typical examples were selected for each rock type. The typical samples were chosen from as wide a geographical range as possible in case there were gross lateral variations which were not readily apparent megascopically.

After preliminary examination, 77 thin sections were chosen for modal analysis. These were selected to encompass the apparent range in composition for each major rock type except those for which modal analyses of ordinary thin sections were obviously of little value (e.g. quartz-pebble meta-conglomerate, pegmatite). Modal analyses of one or two typical examples of minor rock types were also carried out. A Leitz mechanical stage which moves 0.5 mm per click stop was used. Traverses across the thin sections were spaced so as to cover the whole thin section, an area of about 700 to 800 square mm in most cases, and 1,000 points were counted per section. The average apparent grain diameter in thin sections for which modal

analyses were carried out is estimated to be 0.5 mm or less, i.e. 1,000 points equals or nearly equals 1,000 grains, except for some amphibolite, knobby biotite-plagioclase gneiss, biotite-cordierite-sillimanite gneiss, pyroxene amphibolite, epidiorite, western granitic rocks, and eastern granitic rocks. The most coarse-grained thin section for which modal analysis was carried out (amphibolite, 624-67-9a) has an estimated average apparent grain area of 8 square mm, so that it contains only about 1000 grains. All other thin sections of the coarser-grained rocks used for modal analysis are estimated to contain a minimum of 200 grains and generally at least 300 to 400 grains. The range of composition for the thin sections for which modal analysis was carried out should encompass the total range of composition for each major rock type. For those rock types for which the thin sections show little variation in composition (e.g. unit 10, epidiorite) the mean or average value for the modal analyses should approximate the mineralogical bulk composition of the unit.

APPENDIX II X-RAY FLUORESCENCE ANALYSIS

The 35 samples selected for analysis* were prepared in the same fashion as the whole-rock samples used for Rb-Sr dating (Appendix VI), except that they were not diluted with cellulose and a very small quantity of detergent was added as a binder before briquetting.

The briquettes were mounted in Norelco X-ray fluorescence equipment. The operating conditions are summarized in Table XIX. In all cases the $K_{\alpha 1}$ peak and a background reading were measured, and a corrected reading in counts per second obtained by subtracting the background from the peak.

Ideally, the corrected reading in counts per second would be directly proportional to the weight per cent of the element and the latter could be obtained by comparison with a standard sample, within limits imposed by instability in the instrumentation and any other possible source of fluctuation in the counting rate. In actual practice, however, each sample exhibits a different degree of mass absorption (dependent on the elements present) for every wave length of secondary radiation. Hence in general the accuracy of the determination of a given element depends on how closely the sample analyzed resembles the standard sample chemically.

The percentages of Rb and Sr may be corrected for mass absorption by using the Compton peak (Reynolds, 1963). His procedure was followed using G-1 as a comparison standard. The values of Rb 220 ppm, Sr 280 ppm (Fleischer and Stevens, 1962) were accepted for the standard. With this correction the precision (Table XX) should give a measure of the accuracy of these determinations. Reynolds estimates the accuracy to be $\pm$ 3 per cent. The Rb-Sr dating (see Appendix VI) suggests that the Sr percentage (determined by the first method discussed in Appendix VI) may be systematically low.

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* Na_2O was determined chemically on a portion of the powdered sample by Technical Services Laboratories, Toronto. Accuracy is reported to be better than 2 per cent in general.

Table XIX Operating Conditions for X-ray Fluorescence Analysis

Element	"Target"	Time	Xtal	Ctr	CtrV	X-RP	PHA	PHLV	PHWV
Mg	Cr	100	ADP	F.P.	1500	Vac.	Diff.	3	6
Al	Cr	10	EDDT	F.P.	1500	Vac.	Diff.	4	8
Si	Cr	10	EDDT	F.P.	1540	Vac.	Diff.	6.5	7.5
K	W	20	EDDT	F.P.	1480	Vac.	Diff.	6	8
Ca	W	20	EDDT	F.P.	1510	Vac.	Diff.	8	15
Ti	W	50	LiF	F.P.	1485	Air	Diff.	10	15
Mn	W	50	LiF	F.P.	1470	Air	Diff.	5	20
Fe	W	20	LiF	F.P.	1500	Air	Int.	1.5	--
Rb	Mo	-	LiF	Sc.	820	Air	Int.	1.5	--
Sr	Mo	-	LiF	Sc.	820	Air	Int.	1.5	--

Explanatory notes:

"Target" - Target tube. Operating conditions 50 KV, 30 MA for chromium tube (Cr), 50 KV, 40 MA for tungsten (W) and molybdenum (Mo) tubes.

Time - Time in seconds for one determination of a peak or background. Peaks were determined twice and backgrounds once. For Rb and Sr see the first procedure for Rb and Sr determination given in Appendix VI.

Xtal - Analyzing crystal. ADP, ammonium dihydrogen phosphate; EDDT, ethylene-diamine-tartrate; LiF, lithium fluoride.

Ctr - Counter. F.P., flow proportional; Sc, scintillation.

CtrV - Counter voltage.

X-RP - X-ray path. Vac., vacuum.

PHA - Pulse height analyzer. Diff., differential; Int, integral.

PHLV - Pulse height level voltage

PHWV - Pulse height width voltage

The magnitude of the mass absorption factor for Al_2O_3, Fe_2O_3, MnO, TiO_2, CaO, and K_2O may be estimated by comparing the factors necessary to convert counts per second for W-1 and G-1 respectively into weight per cent. The ratio of the W-1 factor: G-1 factor for these elements is shown in the following table ("mass absorption factor") with the precision and detectability for all elements. The precision (expressed as a percentage) is the standard deviation of the standard sample divided by the mean value times 100 i.e. $\frac{S.D}{Mean} \times 100$. The detectability is the amount of an element, expressed in weight per cent, which gives a number of counts per second greater than three standard deviations above the background.

Table XX Statistical Data for X-ray Fluorescence Analysis

	Precision (%)	Detectability (wt %)	"Mass absorption factor"
MgO	4.45	0.41	——
Al_2O_3	0.95	0.18	0.98
SiO_2	0.72	0.13	——
K_2O	0.62	0.002	0.89
CaO	0.86	0.007	0.90
TiO_2	0.88	0.0009	1.03
MnO	0.68	0.0004	1.06
Fe_2O_3	0.66	0.001	1.02
Rb	1.32	5 ppm	——
Sr	1.34	6 ppm	——

In order to minimuze the mass absorption factor, W-1 was used as a standard for the determination of K_2O, CaO, TiO_2, MnO, and Fe_2O_3 for the samples which resembled it chemically, that is, those classified as hornblende-biotite gneiss, amphibolite, and epidiorite. G-1 was used as a standard for all of the other samples. As the precision is less than one per cent for all major elements (except MgO), the

"mass obsorption factor" gives a measure of accuracy, provided the determinations for the standard samples are correct. The accuracy, for any sample whose composition is intermediate between G-1 and W-1 is, therefore, probably no worse than 11% for K_2O, 10% for CaO, 3% for TiO_2, 6% for MnO, 2% for Al_2O_3, and 2% for Fe_2O_3 and in most cases should be less than half these figures. In favorable cases (e.g. samples whose mass absorption is nearly identical with the standard) the accuracy will approach the value for precision.

The percentage of MgO has been corrected for mass absorption by use of a calibration curve set up with three chemically analysed standards, a shale, W-1 and a meteorite. These standards do not fall on a smooth curve and the accuracy for MgO is estimated to be in the order of 15 per cent. The percentage of SiO_2 has been determined with a similar curve using W-1, G-1 and pure SiO_2 as standards. A smooth curve was obtained. The accuracy is difficult to estimate, but is believed to be generally no worse than about 5 per cent in view of the totals obtained for analyses (generally between 97 and 102 per cent) and the major role SiO_2, the most abundant element, plays in arriving at these totals.

APPENDIX III NORMATIVE CALCULATIONS

A. Barth Mesonorms

Barth (1959) fully discusses his mesonorm, which was constructed for rocks belonging to the mesozone of regional metamorphism. The writer has followed his method with the following exceptions:

1. Ap and Cc were not calculated.
2. If Ti (titanium) was in excess over Ca, the excess Ti was calculated as Il (ilmenite). This case was not considered by Barth.
3. As total iron was obtained, a certain percentage had to be assigned to Mt (magnetite) somewhat arbitrarily. Ratios of Fe in magnetite to total Fe were calculated from appropriate analyses of average rocks given in Poldervaart (1955) and the following ratios were adopted.
   a. For unit 8 (except sample 624-24-9): all of Fe assigned to magnetite (Mt) (See Poldervaart, 1955, p. 135, index no. 48).
   b. For units 1 and 4, and samples 624-24-9 and 614-19-7: 0.6 of Fe assigned to magnetite (Mt) (ibid, p. 135, index no. 50)
   c. For all other samples: 0.4 of Fe assigned to Mt (ibid, p. 135, index no. 61 and no. 68).

B. C. I. P. W. Norms

The procedure followed is that given by Johannsen (1939, p. 88-98), with the following exceptions:

1. Z, hl, th, nc, ap, fr, pr and cc were not calculated.
2. Arbitrary ratios of FeO: total Fe (as FeO) were adopted from Poldervaart's (1955) data for the appropriate igneous rocks, as the metamorphosed samples were to be compared with igneous rocks. The remaining Fe was converted to Fe_2O_3 and combined with the appropriate FeO to form mt. The ratios adopted were:
   a. For rocks in units 2, 6, and 10: 0.76 (from Poldervaart, average diorite 0.745, average tholeiite 0.78, average alkali basalt 0.75).
   b. For rocks in unit 4: 0.40 (average rhyolite 0.40)
   c. For 614-40-8b and the rocks forming units 12 and 13: 0.67 (average granite 0.65, average granodiorite 0.68)
   d. For rocks in unit 14: 0.65 (average granite 0.65).

APPENDIX IV A'KF' AND A'C'F' DIAGRAMS

These diagrams are modifications of Eskola's (1922) ACF diagram and the somewhat similar AKF diagram. In the original diagrams and the writer's modifications of these all components are expressed in molecular and not in weight proportions. Rules for calculating the ACF diagram are given in Eskola (1922, p. 157). To summarize these, after corrections are made for the FeO, Fe_2O_3, and CaO in modal ilmenite, modal magnetite, modal sphene, calcite and apatite, then A = Al_2O_3 + Fe_2O_3 - (K_2O + Na_2O); C = CaO; and F= FeO + MgO + MnO. For the AKF diagram, presumably after corrections for ilmenite and magnetite (the writer was unable to find a discussion of this in the literature), A = Al_2O_3 + Fe_2O_3, K = K_2O, and F = FeO + MgO + MnO. These diagrams are admirably suited for a comparison of mineralogical and chemical composition of a given sample, the purpose for which they were intended. However, they are not nearly as well suited for a comparison of metamorphic rocks with the rocks they may have been derived from, and in addition the ACF diagram cannot be used in any meaningful way for plotting rocks containing abundant calcite or feldspars other than anorthite. On both the ACF and AKF diagrams, the position at which a given sample is plotted depends in part on the oxidation state of the iron, and this in turn varies with the degree and conditions of metamorphism. An extreme example of this would be an hematite-bearing rock (iron formation, say) which lacked Al_2O_3, CaO, MgO, and MnO. This would plot at A on the ACF diagram. A sample containing the same amount of iron as magnetite would plot along the AF boundary one-third of the way from the A corner. With regard to rocks with abundant feldspar, because Na_2O is subtracted from Al_2O_3 in the ACF diagram, a rock containing, for example, 90 per cent sodic oligoclase (An_{11}) and 10 per cent hornblende would plot in almost exactly the same position as a rock containing 50 per cent anorthite (An_{100}) and 50 per cent hornblende.

The A'C'F' and A'KF' diagrams used by the writer are not suited for a compar-

ison of chemical composition and mineral assemblages, but are much more suitable for a comparison with possible source rocks, as they avoid the difficulties mentioned above.

On these diagrams A = Al_2O_3, F = total iron (as FeO) + MgO + MnO, C = CaO, and K = K_2O. On both, iron formation would be plotted in the F corner. Calcite-rich assemblages can be plotted in a meaningful way and rocks rich in sodic plagioclase and potassium feldspar are readily distinguishable from more basic rocks on the A'C'F' diagram.

APPENDIX V : SAMPLE PREPARATION AND EXPERIMENTAL DATA

K-Ar DATING

MINERAL SEPARATION AND ANALYSIS

Four biotite separates, two muscovite separates, and two hornblende separates were prepared from samples of various rock types, using methods similar to those discussed by Peterman (1962, p. 166-170). These separates are described in Table XXI.

Table XXI : Minerals dated by the K-Ar method

University of Alberta No.	Description
AK 350	90% fresh muscovite, 6% interleaved biotite, 4% quartz. Size between -80 and -120 mesh. From biotite-muscovite-quartz schist, sample 614-47-9. *
AK 351	98% fresh green hornblende, about 0.5% biotite, the remainder mainly plagioclase. Size between -80 and - 120 mesh. From hornblende quartz diorite, sample 614-44-10.
AK 352	96% fresh deep green hornblende, 4% attached biotite flakes. Size between -80 and -120 mesh. From granitic gneiss, sample 614-S1.
AK 353	98% brown biotite, inclusions of 1% hornblende and 1% K-feldspar. Size between -80 and -120 mesh. From granitic gneiss, sample 614-S1.
AK 354	98% biotite, 2% interleaved muscovite. Both seem fresh but there is a little iron oxide staining. Size between -80 and -120 mesh. From biotite-muscovite-quartz schist, sample 614-47-9.
AK 355	96% biotite, 4% inclusions of hornblende. Fresh apart from minor iron stain. Size between -120 and -160 mesh. From hornblende-biotite gneiss, sample 614-S3.
AK 356	98% biotite, impurities mainly plagioclase. Biotite unweathered but some pleochroic haloes were noted. Size between -60 and -120 mesh. From pegmatite, sample 614-41-6b.
AK 357	99% fresh muscovite, impurities quartz and K-feldspar. Size between -80 and -120 mesh. From meta-arkose, sample 614-30-8a.

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* The locations from which the samples were collected and what additional information is available on the samples are tabulated in Appendix VII and Appendix VIII. Sample locations are also shown on Figure 7.

Potassium was determined using tetraphenylboron precipitation for biotite and muscovite (Peterman, 1962, p. 171) and the Perkin-Elmer flame photometer for hornblende (ibid., p. 172). Rubidium in the tetraphenylboron was corrected for by X-ray fluorescence techniques. The results of all determinations are shown in Table XXII.

Table XXII : Percentage of K^{40}

AK No.	Mineral	Sample Weight gms	KRbTPB gms	K_2O ppm
350	Muscovite	0.2425	0.1760	--
351	Hornblende	0.4988	--	54.5
352	Hornblende	0.5083	--	70.0
353	Biotite	0.2478	0.1538	--
354	Biotite	0.2537	0.1560	--
355	Biotite	0.2500	0.1342	--
356	Biotite	0.2510	0.1409	--
357	Muscovite	0.2522	0.1972	--

AK No.	Mineral	K_2O+Rb_2O %	Rb_2O %	K_2O[1] %	K^{40}[3] ppm
350	Muscovite	9.416	0.037	9.395	9.416
351	Hornblende	--	--	1.095	1.097
352	Hornblende	--	--	1.377[2]	1.380
353	Biotite	8.115	0.086	8.066	8.084
354	Biotite	8.079	0.097	8.024	8.042
355	Biotite	7.055	0.073	7.013	7.028
356	Biotite	7.376	0.097	7.321	7.337
357	Muscovite	10.27	0.069	10.23	10.25

Analyst: P.L. Money

1. Rb_2O weighed as K_2O. Correction for $K_2O = (0.57)\ (Rb_2O)$
2. A correction for biotite (4% in sample, K_2O percentage 8.066) reduces the K_2O content from 1.377 to 1.053% for the hornblende, and reduces ppm K^{40} to 1.055.
3. ppm $K^{40} = 1.0022\ (\%K_2O)$; K^{40} assumed to be 0.0118 atomic per cent of total K.

Argon was extracted in a flux-fusion system using the same technique as that described by Peterman (1962, p. 172-175). Isotopic measurements were done by H. Baadsgaard with a 6- inch 60°Nier type mass spectrometer tube using the dynamic technique. This is described by Peterman (1962, p. 175-176). The results are shown in Table XXIII.

Table XXIII : Percentage of Ar^{40} and radiogenic argon

AK No.	Mineral	Ar^{40} ppm	Radiogenic Argon (per cent)
350	Muscovite	1.619	99.9
351	Hornblende	0.2067	98.4
352	Hornblende	0.2528	97.9
353	Biotite	1.350	99.9
354	Biotite	1.442	99.3
355	Biotite	1.009	99.9
356	Biotite	1.181	99.2
357	Muscovite	1.694	99.3

EXPERIMENTAL ERROR

In replicate determinations of potassium at the University of Alberta by the tetraphenylboron precipitation method a precision (one standard deviation) of ± 2 per cent has been attained. Using the Perkin-Elmer flame photometer a precision of ± 3 per cent has been attained. Precision for Ar^{38} for the argon spike set used in this work is ± 1 per cent. The precision in Ar determinations is of the order of ± 2 per cent, as the chart can be read only to ± 1 per cent. On the basis of these figures the K-Ar ages reported are considered to have a precision of ± 5 per cent.

APPENDIX VI : SAMPLE PREPARATION AND EXPERIMENTAL DATA, Rb-Sr DATING

SAMPLE PREPARATION

All Rb-Sr determinations were made on whole rock samples. Weathered parts of the samples were removed and the samples were then crushed in a DFC jaw crusher. The crushed samples were coned and quartered until a sample of about 100 grams was obtained. This was then crushed with a Bico pulverizer and quartered until a sample of about 5 to 10 grams was obtained. This was crushed in a Bleuler rotary mill or a Pica blender mill. Part of the resulting powder was used to make a briquette for determining Rb:Sr ratios by X-ray fluorescence and part was used for Sr extraction and subsequent determination of Sr isotope ratios. The samples selected for dating are tabulated on Figure 9. Sample locations are shown on Figure 7. Refer to Appendix VII and Appendix VIII for further information on these samples.

DETERMINATION OF Rb:Sr RATIOS

The parts of the powdered samples selected for briquetting were diluted 1:1 by volume with cellulose powder in a Pica blender mill. This corresponds to approximately 9 parts sample to 1 part cellulose by weight. The samples were backed by cellulose powder and briquetted in an Applied Research Laboratories Inc. Briquetting machine Type 4451 for 60 seconds at 30,000 p.s.i.

The briquettes were mounted in Norelco X-ray fluorescence equipment. The radiation source was a Mo target tube energized by 50 K.V. and 40 M.A. An LiF analysing crystal, scintillation counter, and air path were used. Two different measuring procedures were used.

In the first, the pulse height analyser was set at integral and the pulse height level voltage at 1.5. The time for 10^5 counts was determined for the Rb $K\alpha$ and Sr $K\alpha$ peaks, for a background reading half-way between the peaks, and for background readings at 2θ positions equally far from the Rb and Sr peaks in the opposite

direction from the first background reading, e.g. the goniometer readings for the run were Rb peak, 26.53°; Sr peak 25.03°; B.G. I, 27.28°; B.G. II, 25.78°; B.G. III, 24.28°. The peaks and background readings were converted into counts per second, B.G. I and B.G. II were averaged and subtracted from Rb, and B.G. II and B.G. III averaged and subtracted from Sr. The Rb/Sr count per second ratio was then computed and corrected to the true Rb/Sr ratio. The correction factor is that required to convert the XRF Rb-Sr ratio to the isotope dilution ratio for G-1 and five other samples which had been analysed by the standard isotope dilution method. The data for the standards is tabulated below:

Standard sample	XRF Rb/Sr ratio (run 1)	XRF Rb/Sr ratio (run 2)	Isotope dilution Rb/Sr ratio	Isotope dilution ratio/XRF ratio (run 1)	Isotope dilution ratio/XRF ratio (run 2)
JG-59-93-1[1]	.0683	.0697	.0861	1.26	1.24
JG-60-500-3	.206	.209	.255	1.24	1.22
JG-60-74-2	.356	.361	.429	1.20	1.19
JG-60-64-1	.488	.500	.627	1.29	1.25
JG-60-79-3	.712	.716	.873	1.23	1.22
JG-60-62-2	1.41	1.48	1.42	1.08	1.03
G-1	.702	.703	.868	1.24	1.23
(10 runs)	.693	.706		1.25	1.23
	.705	.704		1.23	1.23
	.716	.706		1.21	1.23
	.697	.701		1.25	1.24

G-1: Mean value for isotope dilution Rb:Sr/XRF Rb:Sr 1.234
Standard deviation 0.011

<u>Other standards (disregarding JG-60-62-2)</u>: Mean value for isotope dilution Rb:Sr/XRF Rb:Sr 1.234
Standard deviation 0.029 (2.4 per cent of the ratio)

[1] Standard samples from N.E. Alberta except G-1. Isotope dilution analysis by H. Baadsgaard except G-1.

It would seem that this method is acceptable for samples with a range of XRF Rb/Sr ratios of about 0.068 to 0.716. It has been used for such samples in the present thesis and for the one sample with an XRF ratio of less than 0.068.

A precision of 4.5 per cent has been assumed for ratios determined by this procedure. This is considerably higher than the standard deviation. It includes the

largest deviation from the mean value and hence should include the true isotope dilution Rb/Sr ratio.

For samples with Rb/Sr XRF ratios above 0.7 the above method is not useable and another method was adopted. It had been assumed, in using the above method, that the background correction under the Rb and Sr peaks is linear. This is not the case, as the background is non-linear (curved upward) under the Sr peak (Fairbairn, 1963, p. 135). The correction due to this appears to be negligible up to an Rb/Sr ratio of about 0.7 (see tabulated data above). Rocks with such ratios normally contain a large amount of Sr (in the order of 200 ppm). However, in general, samples with higher Rb/Sr ratios owe these not to very high Rb but instead to low Sr and the precise measurement of the baseline becomes critical. A contributory factor may be the difficulty of determining the exact position of the Sr peak above a sloping background, as the highest counting rate does not necessarily indicate the exact peak position. Both factors tend to decrease the measured amount of Sr, giving too low an apparent age. Accordingly, for such samples Rb and Sr peaks were measured directly on the chart, using Mo-radiation and the same tablets as for the first method. Following Fairbairn (1963) each sample was run several times on each of two consecutive days, with a single run of G-1 between all samples. In total each sample was run eight to ten times. The ratio ("K") of the Rb/Sr isotope dilution ratio to the Rb/Sr XRF ratio for G-1 was used to "normalize" the mean value of the XRF ratio for each sample. Fairbairn (1963) found that "K" fluctuated from day to day. In the present work, "K" was constant (within a standard deviation) so that the data for the two runs has been combined for statistical purposes. Analytical error is difficult to evaluate using the procedure. Standard deviation for the standard and the samples can be readily computed. However, there is evidence (Fairbairn, 1963) that the conversion factor ("K") from XRF ratios to isotope dilution ratios as found by this method is not constant. Fairbairn investigated this factor in 19 samples which had been analysed by isotope dilution. Sixteen of the 19 have smaller conversion factors

than G-1; the range is 1.02 to 0.886 of the factor for G-1. Hence, based on this data, if "K" for G-1 is used, in most cases the apparent Rb/Sr ratio becomes too large and the rocks have apparent ages which are too young. The writer, in the course of the present work, decided to adopt G-1 as a standard but to include an "error" in the plotted points which is large enough to include the apparent variation in "K". As the error is probably entirely in the direction of too young an apparent age, the true age of the samples analysed (Figure 9) is probably between the point plotted and the upper limit (of age). The writer re-tabulated Fairbairn's (1963) data, and found that of the 14 samples containing more than 50 ppm Sr, 12 had conversion factors within 6 per cent of that for G-1. Most of the samples dated by the writer contain more than 50 ppm Sr and accordingly an error of 6 per cent was adopted for these. Three samples (614-40-8a, 614-78-18, and 624-Y-7) contain less than 50 ppm Sr. Fairbairn analysed 5 samples containing less than 50 ppm Sr; all differ in conversion factor from G-1 by more than 6 per cent. The maximum difference is about 11 per cent, but as this sample contains only 14 ppm Sr and the minimum amount in the writer's samples is 32 ppm (614-78-18) an "error" of 10 per cent was assumed for the three samples with less than 50 ppm Sr. The apparent ages of these three samples (using the G-1 conversion factor) are less than those for the other samples which probably have the same true age, as would be expected on the basis of Fairbairn's (1963) data. It should be noted that the writer could find no direct correlation between Rb/Sr ratios or the Rb content and variations in the conversion factor.

The adopted errors, as a percentage of the Rb/Sr ratio for these samples, are tabulated below. These are the sum of a standard deviation for the sample, and the "error" discussed above, combined by the method suggested in Topping (1957, p. 81). Sr contents in ppm are also tabulated.

Sample No.	No. on Figure 9	Sr ppm	Assumed error (per cent)
614-19-1c	8	91	6.8
614-22-9	11	58	7.4
614-30-8a	4	66	6.9
614-40-8a	1	37	12.3
614-78-18	12	32	12.1
614-102-1b	3	63	7.6
624-Y-7	9	36	14.5
644-Y3-9b	13	55	8.2

The Rb/Sr ratios have been converted to Rb^{87}/Sr^{86} ratios by using the known abundance of Rb^{87} in normal Rb and the known abundance of Sr^{86} in normal Sr and by correcting for the radiogenic Sr^{87} in each sample. The results for all samples are shown in Table XXIV.

Table XXIV : Rb/Sr and Rb^{87}/Sr^{86} ratios in samples used for Rb/Sr dating

Sample No. and Map Unit	Rb/Sr (XRF)	Rb/Sr "normalized"[1]	Rb^{87}/Sr^{86}
614-40-8a (1)	2.54	3.29	9.74 ± 1.20
614-40-8b (1)	0.277	0.342	0.987 ± 0.044
624-102-1b (1)	1.74	2.25	6.58 ± 0.50
614-30-8a (1?)	2.14	2.77	8.21 ± 0.56
614-24-12 (2)	0.144	0.178	0.513 ± 0.023
614-36-5 (2)	0.226	0.278	0.804 ± 0.036
614-95-4 (4)	0.411[2]	0.507	1.47 ± 0.06
	0.396[3]	0.513	1.48 ± 0.10
614-19-1c (5)	0.977	1.26	3.69 ± 0.25
624-Y-7 (5)	3.12	4.04	12.01 ± 1.74
614-28-6 (12)	0.837[3]	1.08	3.16 ± 0.22
	0.889[2]	1.10	3.19 ± 0.14
614-22-9 (12)	1.97	2.55	7.54 ± 0.56
614-78-18 (12)	2.92	3.78	11.26 ± 1.36
644-Y3-9b (12?)	1.20	1.55	4.58 ± 0.37
614-85-1 (13)	0.0324	0.0400	0.116 ± 0.005
614-31-8 (13)	0.0807	0.0996	0.288 ± 0.013
614-41-6b (14)	0.0895	0.110	0.319 ± 0.014

1. see the preceding discussion
2. by the first method (2 peaks, 3 background readings)
3. by the second method (measurement on chart)

It should be noted that the Rb^{87}/Sr^{86} ratio for samples 614-95-4 and 614-28-6, as determined by the two methods, are much closer than the reported "error". It appears that adoption of the two different methods does not introduce a systematic error into the results.

STRONTIUM EXTRACTION AND ISOTOPE MEASUREMENT

Whole rock samples weighing approximately 0.25 to 0.5 grams were weighed into Teflon beakers. They were then treated with 10 ml 1:1 HNO_3, 10 ml HF, and 1 ml H_2O and evaporated to dryness (110°C). The residue was moistened with H_2O,

5 ml HNO_3 was added, the residue was evaporated to dryness and then baked (200°C). Then the residue was moistened with H_2O, 5 ml of re-distilled 6 M HCl was added, this was evaporated to dryness and the sample baked. Less than 2 ml of 2.5 N HCl was added and the resulting solution centrifuged. The supernatant liquid was added to a clean, prepared ion exchange column (10 inches high, 13 ml Dowex 50W-X8, 200-400 mesh, resin). 2.5 N HCl was passed through the column, and the 55 to 68 ml fraction collected, as well as 8 ml fractions on either side of this as a check. The 55-68 ml fraction contains most of the Sr. The Sr fraction was evaporated to dryness, treated with a droplet of $HClO_4$, and the excess $HClO_4$ fumed off. The Sr perchlorate was then loaded on a tantalum mass spectrometer filament and this was outgassed at 1.5A filament current. The instrument used was a 6-inch, 60° solid source mass spectrometer. Sr^{86}, Sr^{87}, Sr^{88}, and Rb^{85} peaks and the "zero" positions were recorded on a strip chart recorder. Where necessary, Rb^{85} was used to compute Rb^{87} and to correct the Sr^{87} total. The ratio Sr^{86}/Sr^{88} was computed and "normalized" to 0.1194 to obtain a mass discrimination correction. The ratio Sr^{87}/Sr^{86} was computed and corrected for mass discrimination. The results are shown in Table XXV.

Table XXV: Sr^{87}/Sr^{86} ratios in samples used for dating

Sample No.	Sr^{87}/Sr^{86} measured	Sr^{86}/Sr^{88} measured	Sr^{87}/Sr^{86} "normalized"[1]	Standard deviation Sr^{87}/Sr^{86}
614-40-8a (1)	0.949	0.1174	0.941	0.004
614-40-8b (1)	0.730	0.1200	0.732	0.002
624-102-1b (1)	0.866	0.1198	0.868	0.002
614-30-8a (1?)	0.946	0.1194	0.946	0.004
614-24-12 (2)	0.722	0.1183	0.718	0.002
614-36-5 (2)	0.727	0.1188	0.725	0.001
614-95-4 (4)	0.746	0.1174	0.739	0.002
614-19-1c (5)	0.805	0.1187	0.802	0.003
624-Y-7 (5)	0.984	0.1189	0.982	0.003
614-28-6 (12)	0.806	0.1194	0.806	0.001
614-78-18 (12)	1.031	0.1209	1.037	0.010
614-22-9 (12)	0.959	0.1187	0.956	0.002
644-Y3-9b (12?)	0.880	0.1180	0.875	0.003
614-85-1 (13)	0.709	0.1194	0.709	0.001
614-31-8 (13)	0.712	0.1191	0.711	0.002
614-41-6b (14)	0.710	0.1196	0.711	0.002

[1] The accepted ratio for the non-radiogenic isotopes Sr^{86}:Sr^{88} is 0.1194. Measured variations from this ratio are believed to be due to mass discrimination by the mass spectrometer. Such variations are used to correct ("normalize") the Sr^{87}:Sr^{86} ratio for mass discrimination.

APPENDIX VII : LOCATIONS OF SELECTED SAMPLES

All samples mentioned in this thesis are tabulated below. The number in brackets after the sample number indicates the map unit the sample is from. The following symbols are used.

P : shown on a plate (see Appendix X)
C : chemical analysis is given (See Appendix XI)
M : modal analysis is given (see Appendix XI)
AK : mineral separate from sample dated by the K-Ar method (see Appendix V and Chapter VI)
RS : sample dated by Rb-Sr method (see Appendix VI and Chapter VI)

			Latitude	Longitude
614-19-1c	(5)	P,C,M,RS	55°58'47"N	106°00'00"W
614-19-7	(5)	P,C,M	56°00'00"N	105°58'49"W
614-19-8c	(5)	P,M	55°59'51"N	105°58'42"W
614-22-9	(12)	P,M,RS	55°50'53"N	105°56'53"W
614-22-19a	(8)	P,C,M	55°50'22"N	105°55'52"W
614-23-8b	(9)	P	55°49'47"N	105°55'40"W
614-24-12	(2)	P,C,M,RS	55°49'35"N	105°54'08"W
614-25-7	(9)	P,C,M	55°49'11"N	105°56'33"W
614-26-5	(8)	M	55°50'42"N	105°54'46"W
614-27-1	(10)	P,C,M	55°49'51"N	105°55'07"W
614-28-6	(12)	P,C,M,RS	55°52'13"N	105°58'47"W
614-28-8	(12)	M	55°52'17"N	105°59'13"W
614-28-11	(2)	P,M	55°52'30"N	105°57'14"W
614-30-4	(7)	P	55°50'36"N	105°53'42"W
614-30-8a	(1?)	P,C,M,AK,RS	55°51'10"N	105°53'28"W
614-31-8	(13)	M,C,RS	55°51'34"N	105°50'00"W
614-33-1	(10)	M	55°51'34"N	105°54'25"W
614-36-5	(2)	P,C,M,RS	55°48'36"N	105°57'41"W
614-37-11	(2)	M	55°47'15"N	105°59'00"W
614-38-5	(8)	P,C,M	55°48'17"N	105°57'08"W
614-38-6	(9)	M	55°48'30"N	105°57'02"W
614-38-9	(11)	P	55°48'00"N	105°55'59"W
614-38-11	(8)	P	55°47'38"N	105°57'00"W
614-38-12	(3a)	M	55°47'41"N	105°57'53"W
614-39-6	(3a)[1]	P,C,M	55°45'11"N	105°59'15"W
614-39-10a	(1)	P,M	55°46'28"N	105°59'48"W
614-40-8a	(1)	P,C,M,RS	55°45'40"N	105°59'23"W
614-40-8b	(1)	P,C,M,RS	55°45'40"N	105°59'23"W
614-40-8c	(1)	M	55°45'40"N	105°59'23"W
614-40-10	(8)	P	55°46'17"N	105°58'32"W
614-41-6b	(14)	C,AK,RS	55°46'00"N	105°52'29"W
614-41-9	(5)	C,M	55°45'04"N	105°53'37"W
614-43-2b	(5)[2]	M	55°48'10"N	105°46'11"W
614-44-10	(-)[3]	M,AK	55°46'43"N	105°49'29"W

[1] Anthophyllite-cordierite-biotite gneiss
[2] Clinopyroxene-bearing hornblende-biotite rock
[3] Hornblende quartz diorite

614-46-6	(8)	P, C, M	55°45'32"N	105°57'35"W
614-46-9	(9)	P, C, M	55°45'00"N	105°58'16"W
614-47-9	(9)	M, AK	55°46'21"N	105°58'12"W
614-49-6	(4)	P	55°47'49"N	105°55'20"W
614-63-4	(2)	P, C, M	55°50'07"N	105°56'24"W
614-64-10	(2)	C, M	55°50'33"N	105°52'41"W
614-67-3	(4)	C, M	55°49'18"N	105°53'42"W
614-69-1	(1)	M	55°51'18"N	105°55'24"W
614-70-3	(8)	M	55°52'39"N	105°52'35"W
614-70-5b	(10)	P	55°52'48"N	105°58'00"W
614-78-18	(12)	M, RS	55°54'27"N	105°55'52"W
614-84-4	(13)	P, M	55°45'00"N	105°47'49"W
614-85-1	(13)	P, C, M, RS	55°48'32"N	105°48'12"W
614-89-4	(6a)	P, C, M	55°47'07"N	105°48'33"W
614-95-4	(4)	P, M, RS	55°55'46"N	105°47'36"W
614-100-1	(6a)	M	55°52'44"N	105°45'47"W
614-101-5	(13)	M	55°52'34"N	105°46'45"W
614-S1	(11)	AK	55°57'00"N	105°51'17"W
614-S2	(14)	C	55°57'00"N	105°51'17"W
614-S3	(2)	M, AK	55°56'55"N	105°51'00"W
624-4-8	(10)	M	55°34'38"N	106°04'51"W
624-5-11b	(1?)	M	55°35'34"N	106°06'24"W
624-10-5	(13)	M	55°31'22"N	106°00'27"W
624-12-8	(10)	M	55°33'55"N	106°07'04"W
624-16-5a	(1?)	M	55°35'17"N	106°07'11"W
624-16-6	(3a)	M	55°35'12"N	106°07'00"W
624-21-5a	(2)	M	55°38'00"N	106°02'33"W
624-21-5b	(4)	P, M	55°38'00"N	106°02'33"W
624-24-6a	(8)	M	55°38'49"N	106°02'16"W
624-24-9	(8)	C, M	55°38'50"N	106°03'05"W
624-24-12	(10)	M	55°39'08"N	106°04'20"W
624-53-5	(12)	C, M	55°40'15"N	106°14'04"W
624-55-3	(2)	M	55°44'39"N	106°00'42"W
624-56-15	(3b)	P, C, M	55°38'05"N	106°06'24"W
624-56-24	(8)	M	55°37'24"N	106°08'12"W
624-57-10	(9)	M	55°40'09"N	106°03'55"W
624-57-29	(8)	M	55°40'29"N	106°03'22"W
624-59-17	(15)	C	55°40'06"N	106°10'57"W
624-62-7c	(1)	P	55°40'55"N	106°05'07"W
624-62-19	(3a)	M	55°42'24"N	106°01'07"W
624-63-12b	(5)	M	55°44'16"N	106°13'52"W
624-65-7	(10)	M	55°39'34"N	106°07'11"W
624-66-6b	(5)	P	55°40'40"N	106°14'38"W
624-67-7	(15)	P	55°39'51"N	106°11'37"W
624-67-9a	(2)	P, C, M	55°39'39"N	106°11'54"W
624-70-6	(15)	P	55°39'04"N	106°11'52"W
624-81-5	(3a)	P, C, M	55°42'45"N	105°59'44"W
624-83-7	(9)	M	55°44'31"N	105°58'22"W
624-84-6	(9)	C, M	55°42'10"N	105°59'50"W
624-88-3	(4)	M	55°40'51"N	106°00'09"W
624-89-5	(9)	M	55°40'09"N	106°02'05"W
624-92-1	(9)	M	55°41'09"N	106°02'45"W
624-97-3a	(12)	M	55°44'54"N	106°05'15"W
624-97-3b	(12)	P, C, M	55°44'54"N	106°05'15"W
624-97-14	(15)	P	55°44'06"N	106°08'03"W

624-102-1b	(1)	M, RS	55°45'00"N	105°59'52"W
624-X-1a	(7)	P	55°30'53"N	106°10'37"W
624-Y-3	(6b)	P, C, M	55°41'24"N	106°10'24"W
624-Y-7	(5)	P, C, M, RS	55°44'06"N	106°13'55"W
634-42-1	(13)	M	55°37'08"N	105°46'43"W
634-52-1	(3b)	P, C, M	55°29'51"N	105°50'52"W
634-55-1	(3b)	M	55°30'41"N	105°56'50"W
634-87-3	(13)	C, M	55°43'16"N	105°50'17"W
634-89-15	(13)	P	55°40'36"N	105°47'19"W
634-98-8	(5)[4]	P	55°44'51"N	105°53'38"W
644-Y2-6	(14)	C	55°43'41"N	106°04'45"W
644-Y3-9b	(12 ?)	RS	55°44'15"N	106°07'41"W

[4]Plagioclase-scapolite-clinopyroxene rock

APPENDIX VIII : SELECTED SAMPLES GROUPED BY MAP-UNIT

All samples mentioned in this thesis are tabulated below by map-unit. The following symbols are used.

P	:	shown on a plate (see Appendix X)
C	:	chemical analysis is given (see Appendix XI)
M	:	modal analysis is given (see Appendix XI)
AK	:	mineral separate from sample dated by the K-Ar method (see Appendix V and Chapter VI)
RS	:	sample dated by Rb-Sr method (see Appendix VI and Chapter VI)

The locations from which these samples were collected are tabulated in Appendix VII.

Map-unit (1)

614-30-8a	P, C, M, AK, RS Meta-arkose from immediately below (?) the base of the Meyers Lake Group. Of uncertain stratigraphic position. May belong to either the "older metamorphic rocks" or the Meyers Lake Group.
614-39-10a	P, M Meta-arkose
614-40-8a	P, C, M, RS Meta-arkose
614-40-8b	P, C, M, RS Cobble from meta-arkose
614-40-8c	M Cobble from meta-arkose. This and the two preceding samples are from the same outcrop.
614-69-1	M Meta-arkose
624-5-11b	M Meta-arkose. Stratigraphic position uncertain (like sample 614-30-8a).
624-16-5a	M Meta-arkose. Stratigraphic position uncertain (like sample 614-30-8a).
624-62-7c	P Meta-arkose. Photomicrograph is of part of a quartz- sillimanite-muscovite segregation.
624-102-1b	M, RS Boulder from meta-arkose.

Map-unit (2)

614-24-12	P, C, M, RS Hornblende-biotite gneiss. From the centre of an area of non-migmatitic hornblende-biotite gneiss about 500 feet wide (too small to show on map) within migmatitic hornblende-biotite gneiss (map sub-unit 11c). Regarded as typical hornblende-biotite gneiss from the eastern fold belt.
614-28-11	P, M Amphibolite from outside of the eastern fold belt. Clinopyroxene-bearing variety.
614-36-5	P, M, C, RS Amphibolite from the eastern fold belt. Regarded as a typical example.
614-37-11	M Hornblende-biotite gneiss, eastern fold belt.
614-63-4	P, C, M Hornblende-biotite gneiss, eastern fold belt. An unusually quartz-rich variety.
614-64-10	C, M Amphibolite from the eastern fold belt. A typical example.
614-S3	M, AK Hornblende-biotite gneiss from outside of eastern fold belt.
624-21-5a	M Hornblende-biotite gneiss, eastern fold belt. Interlayered with acidic meta-volcanic (?) rocks.
624-55-3	M Hornblende-biotite gneiss, eastern fold belt.
624-67-9a	P, C, M Amphibolite from outside of eastern fold belt. An unusually mafic variety.

Map-unit (3)

614-38-12	M Knobby biotite-plagioclase gneiss (sub-unit 3a).
614-39-6	P, C, M Anthophyllite-cordierite-biotite gneiss. A metasomatized rock-type which occurs within sub-unit (3a).
624-16-6	M Knobby biotite-plagioclase gneiss (sub-unit 3a).
624-56-15	P, C, M Biotite gneiss (sub-unit 3b). From eastern fold belt.
624-62-19	M Knobby biotite-plagioclase gneiss (sub-unit 3a).
624-81-5	P, C, M Knobby biotite-plagioclase gneiss (sub-unit 3a).
634-52-1	P, C, M Biotite gneiss (sub-unit 3b) from outside of the eastern fold belt. From a 300-foot wide (not shown on map) area of non-migmatitic biotite gneiss and schist within migmatitic biotite gneiss and schist (map sub-unit 11c).
634-52-1	M From a small body of biotite gneiss (not shown on map) outside of the eastern fold belt.

Map-unit (4)

614-49-6	P
614-67-3	C, M
614-95-4	P, M, RS
624-21-5b	P, M
624-88-3	M

All samples are of acidic meta-volcanic (?) rocks from the eastern fold belt.

Map-unit (5)

614-19-1c	P, C, M, RS Biotite-cordierite-garnet-sillimanite rock. A cordierite-rich variety.
614-19-7	P, C, M Biotite-, garnet-, and sillimanite-bearing quartzo-feldspathic ("arkosic") variety.
614-19-8c	P, M Biotite-cordierite-sillimanite rock.
614-41-9	C, M Clinopyroxene-bearing hornblende-biotite rock.
614-43-2b	M Biotite-garnet-sillimanite rock.
624-63-12b	M Biotite-cordierite-garnet-sillimanite rock
624-66-6b	P Biotite-cordierite-garnet-sillimanite rock
624-Y-7	P, C, M, RS Biotite-cordierite-garnet-sillimanite rock. A garnet rich variety
634-98-8	P, Plagioclase-scapolite-clinopyroxene rock

Map-unit (6)

614-89-4	P, C, M Hypersthene amphibolite (map sub-unit 6a).
614-100-1	M Hypersthene amphibolite (map sub-unit 6a).
624-Y-3	P, C, M Clinopyroxene amphibolite (map sub-unit 6b).

Map-unit (7)

614-30-4	P
624-X-1a	P

Both samples are quartz-pebble meta-conglomerate.

Map-unit (8)

614-22-19a	P, C, M Grey feldspathic quartzite
614-26-5	M Pink feldspathic (arkosic) quartzite
614-38-5	P, C, M Calcareous quartzite
614-38-11	P "Pure" quartzite
614-40-10	P Calcareous quartzite
614-46-6	P, C, M "Pure" quartzite
614-70-3	M Grey feldspathic quartzite
624-24-6a	M Calcareous quartzite
624-24-9	C, M Pink feldspathic (arkosic) quartzite
624-56-24	M "Pure" quartzite
624-57-29	M Calcareous quartzite

Map-unit (9)

614-23-8b	P
614-25-7	P, C, M
614-38-6	M
614-46-9	P, C, M
614-47-9	M, AK
624-57-10	M
624-83-7	M
624-84-6	C, M
624-89-5	M
624-92-1	M

All samples are biotite-muscovite-quartz schist or gneiss.

Map-unit (10)

614-27-1	P, C, M
614-33-1	M
614-70-5b	P
624-4-8	M
624-12-8	M
624-24-12	M
624-65-7	M

All samples are epidiorite.

Map-unit (11)

614-38-9	P Augen gneiss
614-S1	AK Granitic gneiss. Probably a marginal facies of the western granitic rocks (unit 12).

Map-unit (12)

614-22-9	P, M, RS Quartz monzonite
614-28-6	P, C, M, RS Quartz monzonite
614-28-8	M Quartz monzonite
614-78-18	M, RS Quartz monzonite
624-53-5	C, M Quartz monzonite
624-97-3a	M Monzonite
624-97-3b	P, C, M Monzonite from same outcrop as preceding sample.
644-Y3-9b	RS Granitic sill (quartz monzonite?).

Hornblende quartz diorite

614-44-10	M, AK Occurs as inclusions in the eastern granitic rocks (Map-unit 13).

Map-unit (13)

614-31-8	M, C, RS Quartz monzonite
614-84-4	P, M Quartz diorite
614-85-1	P, C, M, RS Quartz diorite
614-101-5	M Quartz diorite
624-10-5	M Quartz diorite
634-42-1	M Granodiorite
634-87-3	C, M Granodiorite
634-89-15	P Granodiorite (?)

Map-unit (14)

614-41-6b	C, AK, RS
614-S2	C
644-Y2-6	C

Map-unit (15)	
624-59-17	C
624-67-7	P
624-70-6	P
624-97-14	P

APPENDIX IX : MINERALOGICAL DESCRIPTIONS

INTRODUCTION

No attempt has been made to provide complete descriptions of the minerals occurring in the rocks of the thesis area as this is outside the scope of the thesis. Certain features noted in the course of flat stage petrographic work, and, in a few cases, further work using the universal stage and index oils, are tabulated in the hope that they may be of some use to future workers. Quartz, muscovite, sillimanite, apatite, zircon, and sphene are not tabulated as they show little if any variation in properties.

The tabulation is by rock type and follows the order in which rock types were discussed in Chapters II and III. The following abbreviations are used:

K-spar	potassium feldspar
Plag.	plagioclase
Biot.	biotite
Chlor.	chlorite
Epid.	epidote
Hrn.	hornblende
Antho.	anthophyllite
Act.	actinolite
Clinopy.	clinopyroxene
Hyp.	hypersthene
Cord.	cordierite
Garn.	garnet
Andal.	andalusite
Opaq.	opaque minerals
Tourm.	tourmaline
Pleo.	pleochroic

MINERALS IN ROCKS BELONGING TO THE "OLDER METAMORPHIC ROCKS" AND PETROLOGICALLY SIMILAR ROCKS (MAP-UNITS 1 to 4)

Meta-arkose

K-spar.:	predominantly well-twinned microcline, a few grains untwinned. A few grains in some thin sections are perthitic.
Plag.:	albite twinning in most grains, a few untwinned or show albite-pericline twins. Composition sodic oligoclase to sodic andesine (An_{12} to An_{33}) in main bodies meta-arkose; sodic oligoclase to calcic oligoclase in meta-arkose[1] immediately below (?) Meyers Lake Group (An_{14} to An_{26}); sodic to intermediate oligoclase in contained cobbles and boulders (An_{14} to An_{19}).
Biot.:	pleo. dark greenish brown to straw yellow.
Garn.:	deep red in hand specimen, colourless in thin section. Isotropic.
Tourm.:	pleo. deep green to almost colourless.
Opaq.:	black in reflected light. Probably magnetite and/or ilmenite.

1. Stratigraphic position uncertain. May belong to the Meyers Lake Group.

Hornblende-biotite rocks and amphibolite

K-spar.: a few grains show microcline twinning, most are untwinned.
Plag.: albite twinning in most grains but a few albite-pericline twin combinations were noted in most thin sections. Carlsbad-albite twins were noted in two sections (out of 21). Compositional range is small (An_{33} to An_{45}).
Biot.: Common type pleo. very dark chocolate brown to stray yellow. Reddish-brown biot. is present in a few sections and the biot. has a greenish cast in two sections of migmatitic hornblende-biotite rocks.
Epid.: most is colourless and has a high birefringence. Pleo. yellow epidote was observed in a few thin sections. Allanite is dark brown and almost isotropic and occurs as separate grains (rarely) or as cores with rims of colourless epidote (commonly). Yellow epidote usually occurs as separate grains but one yellow grain with a colourless rim was noted.
Hrn.: $Z_\wedge c$ = 17° to 24°. Pleo. formula varies from X - yellow brown, Y = bluish green, Z = greenish blue to X - pale brownish, Y = greenish, Z = dark green. There does not seem to be any relationship between variation in $Z_\wedge c$ and pleo. formula. Of 14 thin sections from the eastern fold belt 10 contain "blue-green" hornblende, 4 contain "green" hornblende. Of 7 sections from outside the belt 3 contain "blue-green" hornblende, 4 contain "green" hornblende.
Clinopy.: weakly pleo. colourless to very pale green.
Opaq.: some grains are pyrite (visible in hand specimen). Other grains are rimmed by sphene and are probably ilmenite, some grains may be magnetite.

Knobby biotite-plagioclase gneiss

K-spar.: most grains untwinned but some show microcline twinning.
Plag.: porphyroblasts show albite twins or albite-pericline twin combinations. Smaller grains are untwinned or show albite twinning. Both are sodic oligoclase to sodic andesine (An_{14} to An_{33}).
Biot.: pleo. reddish brown or dark brown to straw yellow.
Hrn.: "blue-green" variety.
Opaq.: in part subhedral and cubic. Black in reflected light. Probably mainly magnetite.

Biotite gneiss and schist

K-spar.: generally shows microcline twinning although a few small grains are untwinned.
Plag.: generally shows albite twins or is untwinned, but albite-pericline twin combinations and Carlsbad-albite twins were noted. Composition ranges from sodic to calcic andesine (An_{32} to An_{45}).
Biot.: pleo. from dark brown with a slight reddish tint to straw yellow.
Hrn.: "blue-green" variety.
Opaq.: anhedral, black in reflected light. Probably magnetite and/or ilmenite.

Acidic meta-volcanic (?) rocks

K-spar.:	in some sections predominantly twinned microcline, in others mainly untwinned. In one section almost every grain is perthitic, in all other sections perthitic grains are rare.
Plag.:	most grains show albite twinning, a few are untwinned. Generally intermediate oligoclase but as calcic as intermediate andesine (An_{38}) in rocks thinly interlayered with hornblende-biotite rocks.
Biot.:	pleo. dark brown or brownish green to straw yellow.
Epid.:	colourless, highly birefringent, rims allanite.
Hrn.:	"blue-green" variety
Opaq.:	in part ilmenite (rimmed by sphene, see Plate V,5), in part probably magnetite, in part pyrite.

MINERALS IN ROCKS BELONGING TO THE "CORDIERITE-GARNET ROCKS" (MAP-UNIT 5)

Biotite-cordierite-sillimanite-(garnet) and biotite-garnet-(sillimanite) schist, gneiss, and granulite

K-spar.:	for the most part shows microcline twinning. In some thin sections almost every grain is perthitic, in others less than half are.
Plag.:	most grains show only albite twins. Carlsbad-albite twinning was seen in one grain. Composition intermediate to calcic oligoclase ("arkosic" varieties); sodic to intermediate andesine ('pelitic" varieties).
Biot.:	pleo. dark or light red brown to straw yellow.
Cord.:	Pale water blue to deep purple in hand specimen. Optically negative. In thin section 614-19-1c, 2V = 84°$\pm$1°. In thin section 624-Y-7, 2V = 83°$\pm$1°. (both determined with universal stage). Many but not all grains show polysynthetic, cyclic, or simple twinning which is on (110) in all cases investigated. Polysynthetic twinning similar in appearance to the albite twinning of plagioclase is the most common type and for a few grains it is impossible to determine if the grain is plagioclase or cordierite. Most of the polysynthetic grains are distinguishable as they show one or more of (1) two sets of polysynthetic twins intersecting at about 60 degrees (Plate VI, 1,2,5-8); (2) marginal alteration to sericite, or a pale green chloritic mineral, or a brownish isotropic mineral; or, rarely, (3) yellow pleo. haloes around zircon inclusions. See Plate VI for illustrations of types of twinning.
Garn.:	deep red in hand specimen, pale pink and isotropic in thin section.
Opaq.:	anhedral to cubic (?), black in reflected light. Probably magnetite and/or ilmenite.

Plagioclase-scapolite-clinopyroxene rocks

Plag.:	large grains are complex twins, probably albite-pericline, small grains show only albite twins. Measurement of 3 extinction angles in the zone normal to 010 suggest the composition is labradorite (about An_{54}).
Scapolite:	uniaxial, optically negative.
Clinopy.:	colourless, probably diopsidic.
Act.:	pleo. weak from pale green to colourless. $Z_{\wedge}c$ = 16°.

Hornblende-biotite-clinopyroxene gneiss

Plag.:	albite twins. Composition calcic andesine (An_{46}).
Biot.:	pleo. red-brown to straw yellow.
Hrn.:	"green" variety.
Clinopy.:	pleo. weak from pale green to colourless. In sample 614-41-9, $N_y = 1.68_2$, $2V = 56° \pm 1°$ indicating a composition of $Ca_{0.94}Mg_{0.92}(Fe^{+2} + Fe^{+3} + Mn)_{0.14}Si_2O_6$ or 80 per cent diopside, 14 per cent hedenbergite, and 6 per cent enstatite (Deer, Howie, and Zussman, 1963, p. 132). The cation contents are probably correct within about 5 per cent.

PYROXENE AMPHIBOLITES

Hypersthene amphibolite (Map sub-unit 6a)

Plag.:	occurs about equally in albite and albite-pericline twins. A weak normal zoning present in a few grains. Composition calcic andesine (An_{46}-An_{47}).
Biot.:	pleo. reddish brown to straw yellow.
Hrn.:	$Z \wedge c = 23°$ to $24°$. Pleo. formula X = light yellowish brown, Y - dark brown, Z = dark olive green.
Hyp.:	pleo. pale green to pale red. In sample 614-89-4, $N_z = 1.74_5$, corresponding to Fs_{64} (ferrohypersthene).
Opaq.:	black in reflected light. Probably magnetite.

Clinopyroxene amphibolite (Map sub-unit 6b)

Hrn.:	pleo. formula X = light brown, Y = dark brown, Z = dark green. $Z \wedge c = 22°$
Clinopy.:	weak pleo. almost colourless in all orientations. $N_y = 1.68_8$, $N_x = 1.67_2$, $2V (+) = 54° \pm 1°$, corresponding to $Ca_{0.90}Mg_{0.94}(Fe^{+2} + Fe^{+3} + Mn)_{0.16}Si_2O_6$ or 74 per cent diopside, 16 per cent hedenbergite, and 10 per cent enstatite. The cations are probably accurate to within 5 per cent. (Howie, Deer, and Zussman, 1963, p. 132).
Opaq.:	cubic, black in reflected light. Probably magnetite.

MINERALS IN ROCKS BELONGING TO THE MEYERS LAKE GROUP (MAP-UNITS 7 TO 9)

Quartz-pebble meta-conglomerate

K-spar.:	mainly well twinned microcline. In three thin sections some grains are perthitic.
Plag.:	in albite twins. Composition sodic to intermediate andesine (An_{32} to An_{38}).
Biot.:	pleo. red brown, dark brown, or almost black to straw yellow.
Chlor.:	pleo. medium green to very pale green. Anomalous blue interference colours.
Garn.:	pale pink and isotropic in thin section.
Opaq.:	many black cubic grains, probably magnetite. Some irregular aggregates rimmed by sphene, probably ilmenite.
Tourm.:	dark olive green in position maximum absorption.

Quartzite, feldspathic quartzite, and calcareous quartzite

K-spar.:	mainly well twinned microcline.
Plag.:	in albite twins. Composition sodic to intermediate andesine (An_{31} to An_{38}).
Biot.:	pleo. red brown to straw yellow except in a granulated rock in which it is pleo. green to straw yellow.
Chlor.:	pleo. pale green to colourless. Anomalous blue interference colours.
Epid.:	zoisite in two of three sections in which it occurs. Probably pistacite in the other.
Act.:	pleo. pale green to very pale yellow. $Z \wedge c$ ranges from 14° to 19°. In sample 614-38-5, $N_x = 1.63$, $N_z = 1.65$, corresponding to an Mg : Fe + Mn ratio of 64 : 36.
Clinopy.:	almost colourless. Presumably diopsidic.
Opaq.:	black in reflected light. Mainly magnetite, lesser ilmenite?
Tourm.:	mainly dark olive green in position maximum absorption. A few grains are blue or have blue patches or cores.

Biotite-muscovite-quartz schist and gneiss

K-spar.:	in part shows microcline twinning, in part untwinned.
Plag.:	in albite twins or is untwinned. Composition sodic to intermediate andesine (An_{31} to An_{38}).
Biot.:	pleo. reddish brown or dark reddish brown to straw yellow.
Andal.:	pale grey in hand specimen. Colourless in thin section.
Opaq.:	black in reflected light. Probably magnetite.
Tourm.:	pleo. generally dark olive green, dark yellow green, or olive brown to almost colourless. Some grains have blue cores, zones, or patches and a few entirely blue grains were noted.

METAMORPHOSED INTRUSIVE ROCKS

Epidiorite (Map-unit 10)

K-spar.:	mainly twinned microcline.
Plag.:	coarse (igneous?) variety almost invariably shows albite-pericline twins, but a few grains are albite or Carlsbad-albite twins; fine (metamorphic) variety commonly shows albite twinning but some grains are untwinned. Composition (both varieties) is intermediate andesine (An_{36} to An_{44}).
Biot.:	pleo. dark brown to straw yellow.
Epid.:	highly birefringent, colourless.
Hrn.:	pleo. from pale brown to bluish green ("blue-green" type) $Z \wedge c = 22°$ to 25°.
Opaq.:	include pyrite (noted in hand specimens) ilmenite (rimmed by sphene), magnetite (black in reflected light, cubic).

METASOMATIZED AND MIGMATITIC ROCKS

Anthophyllite-cordierite-biotite gneiss

Plag.:	generally in albite twins but a few grains are untwinned and a few are probably albite-pericline twins.
Biot.:	pleo. pale red-brown to straw yellow.

Chlor.:	weakly pleo. from pale green to colourless. Weak birefringence in greenish-yellow shade.
Antho.:	colourless, 2V (+) = 82°±1°, N_x = 1.64, N_z = 1.66. Mg is 55 to 80 per cent of Mg + $Fe^{+2}$$Fe^{+3}$ + Mn.
Cord.:	optically negative. 2V (-) = 84°±3°, N_y = 1.54_5. Most grains untwinned, a few show polysynthetic twinning. Yellow pleo. haloes are present around zircon.
Opaq.:	black in reflected light. Magnetite and/or ilmenite.

Porphyroblastic potassium feldspar gneiss and augen gneiss

K-spar.:	in porphyroblasts has well-developed microcline twinning, in matrix commonly has such twinning but a few small untwinned grains were noted. About 25 per cent of the porphyroblasts and 10 per cent of the smaller grains were perthitic.
Plag.:	generally in albite twins, but albite-pericline twins are not uncommon. In one thin section plag. porphyroblasts are anti-perthites. Composition sodic oligoclase to sodic andesine (An_{13} to An_{34}).
Biot.:	commonly pleo. from brown with a slight greenish cast to straw yellow. In two sections pleo. from dark green to straw yellow and in three sections pleo. dark brown to straw yellow.
Chlor.:	pleo. medium to pale green. Has anomalous blue interference colours.
Epid.:	colourless, highly birefringent. Either pistacite or clinozoisite.
Hrn.:	"blue-green" type in all cases.
Opaq.:	black in reflected light. Some grains rimmed by sphene (probably ilmenite), others cubic (probably magnetite).

INTRUSIVE ROCKS

Western granitic rocks

K-spar.:	In part perthitic (string and patch types). Amost invariably shows microcline twinning. A few Carlsbad twins were noted.
Plag.:	most grains show albite twins, a few show albite-pericline twins. Composition sodic to intermediate oligoclase (An_{12} to An_{19}).
Biot.:	pleo. dark brown to straw yellow.
Epid.:	colourless, highly birefringent. Either pistacite or clinozoisite.
Hrn.:	pleo. in blue green to dark green shades. $Z \wedge c$ is 20° to 23°.
Opaq.:	in part probably ilmenite (rimmed by sphene); in part probably magnetite (black, cubic)

Hornblende quartz diorite

Plag.:	generally shows albite twins. Composition sodic andesine (An_{33})
Biot.:	pleo. dark brown to straw yellow.
Epid.:	colourless, highly birefringent. Either pistacite or clinozoisite.
Hrn.:	"blue-green" variety.

Eastern granitic rocks

K-spar.:	large grains in equigranular rocks and megacrysts show microcline twinning. Megacrysts also show Carlsbad twinning. Many small grains are untwinned.
Plag.:	commonly untwinned or shows albite twins. Some albite-

	pericline and Carlsbad-albite twins. Composition calcic oligoclase to sodic andesine (An_{26} to An_{32})
Biot.:	pleo. dark brown to straw yellow.
Epid.:	colourless, highly birefringent. Pistacite or clinozoisite.
Hrn.:	"blue-green" variety.

APPENDIX X PLATES

PLATE I

1. <u>Meta-arkose</u>. Contains cobbles and boulders of medium-grained and very fine-grained quartzo-feldspathic rocks. 55° 45' 40" N, 105° 59' 43" W. Eulas Lake Area (West Half).

2. <u>Meta-arkose</u>. Contains a tightly folded and stretched lens or cobble of amphibolite or hornblende-rich hornblende-biotite gneiss (dark grey). 55° 46' 36" N, 105° 59' 43" W. Eulas Lake Area (West Half). (The lens cap is 2 inches in diameter).

3. <u>Meta-arkose</u>. The disc-shaped areas which stand out on the weathered surface are quartz-sillimanite-muscovite segregations. 55° 40' 52" N, 106° 05' 09" W. Sandfly Lake Area (East Half).

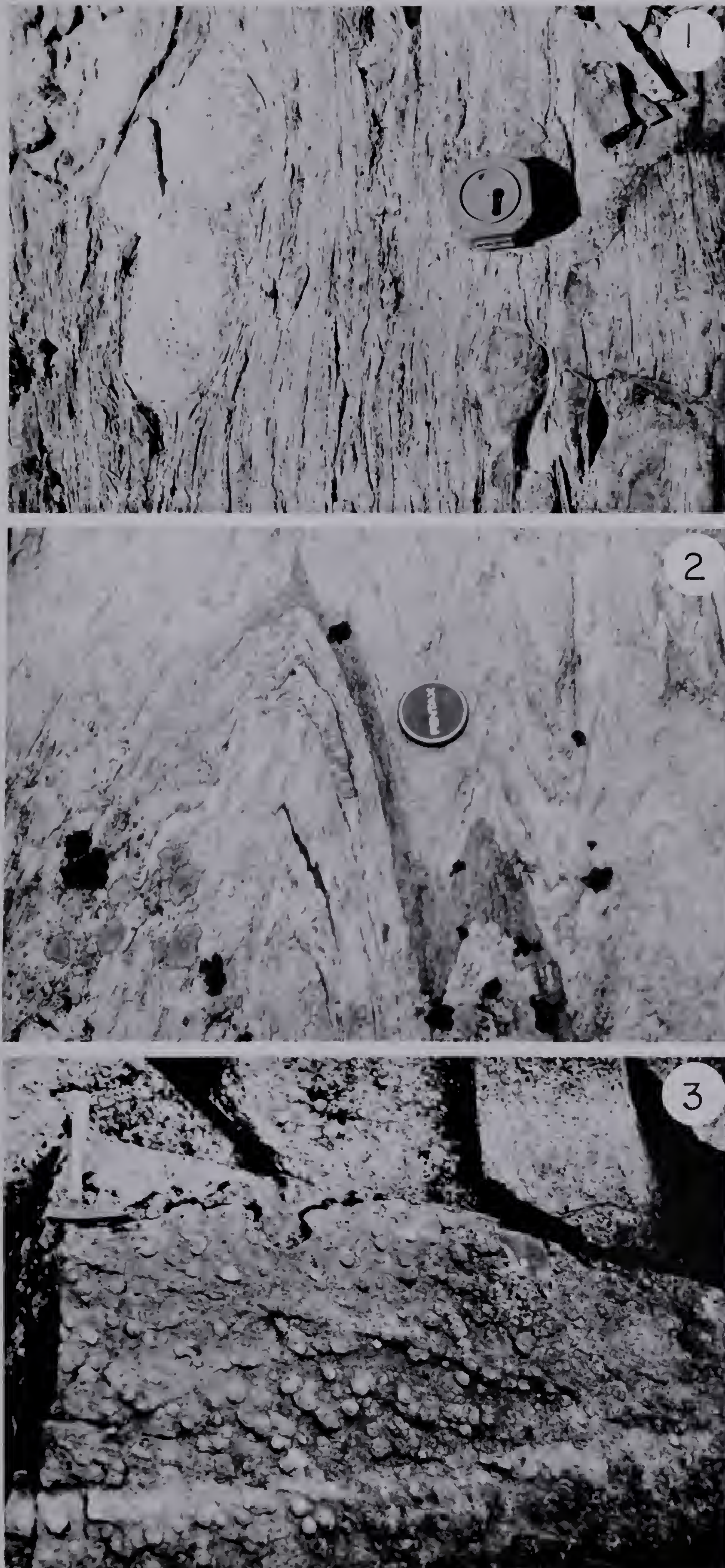
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PLATE II

1. Meta-arkose (unit 1). Thin section 614-40-Ba. Larger quartz grains occur in a matrix of quartz, K-feldspar, muscovite, and minor plagioclase. Crossed nicols. X 25.

2. Meta-arkose. Same view as Plate II, 1. The dark grains are heavily stained K-feldspar. Plane light. X 25.

3. Meta-arkose. Thin section 614-40-8a. K-feldspar (heavily stained) is concentrated in a layer. Other minerals include quartz, muscovite, minor plagioclase, and opaque minerals. The large grain of an opaque mineral to the lower left apparently formed subsequent to the foliation. Plane light. X 25.

4. Meta-arkose. Thin section 624-62-7c. Fibrolite (sillimanite)-quartz-muscovite segregation. The muscovite occurs as small remnants (the largest left of centre) within the fibrolite. Plane light. X 25.

5. Meta-arkose. Thin section 614-30-8a. This is a strongly foliated variety. It consists predominantly of muscovite, quartz and K-feldspar (heavily stained). Minor plagioclase and opaque minerals are present. Quartz and K-feldspar both show elongation parallel to the muscovite flakes. Plane light. X 25.

6. Meta-arkose. Thin section 614-39-10a. Garnet porphyroblasts occur in a matrix of quartz, K-feldspar and muscovite, with minor plagioclase, biotite, and opaque minerals. Plane light. X 25.

7. Boulder from meta-arkose. Thin section 624-102-1b. The abundant dark mineral is stained microcline. A large rectangular grain is cut by quartz-filled fractures. Plane light. X 10.

8. Cobble from meta-arkose. Thin section 614-40-8b. Consists predominately of a granulated aggregate of quartz, microcline, and minor plagioclase and sericite. An area of larger quartz grains (left centre) is present. Crossed nicols. X 10.

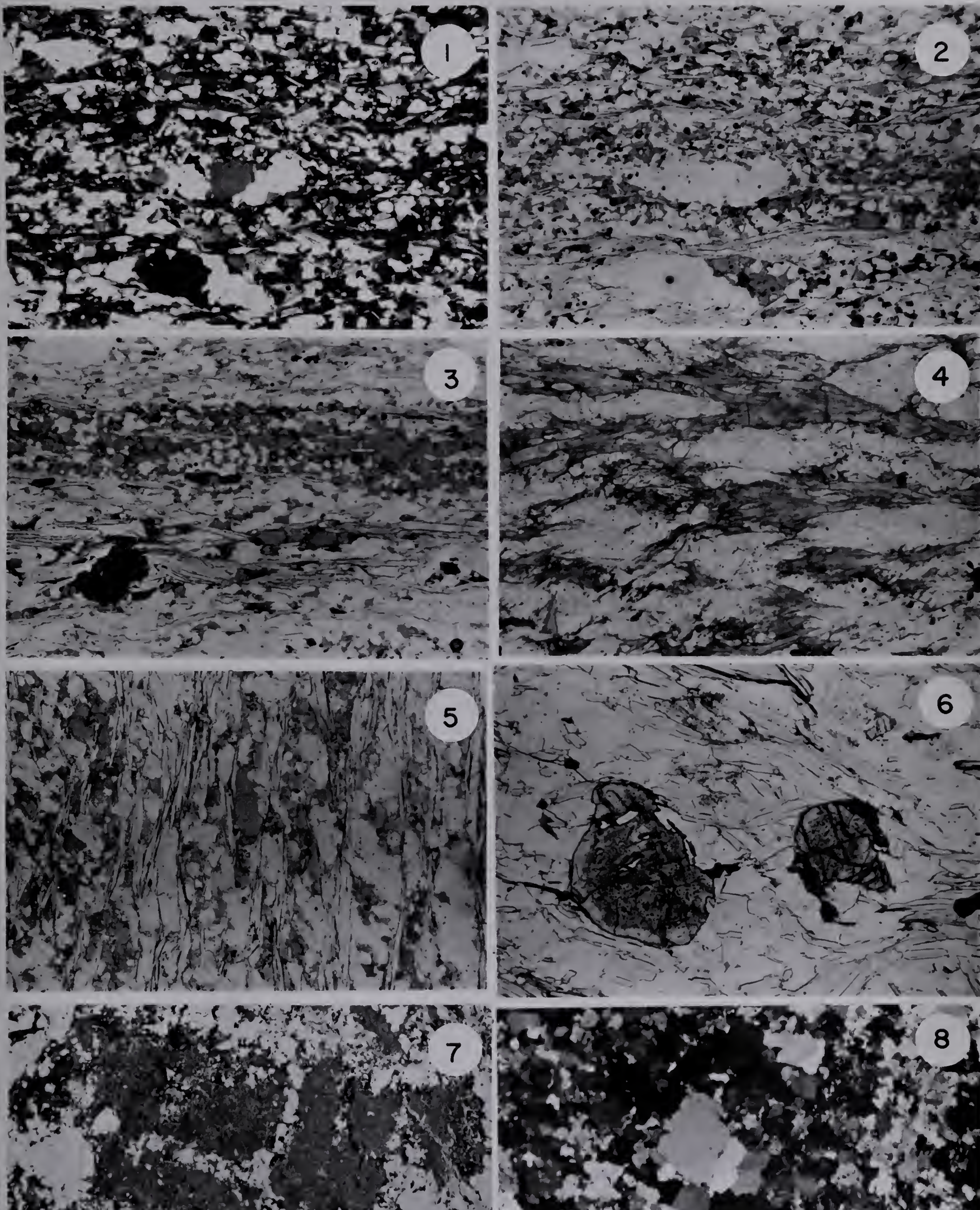
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PLATE III

1. Hornblende-biotite-gneiss (unit 2). Thin section 614-24-12. Shows the general appearance of a typical specimen of this rock type. Dark minerals are hornblende and biotite. Light minerals are mainly plagioclase, with minor quartz and epidote. Plane light. X 25.

2. Hornblende-biotite gneiss. Thin section 614-24-12. An enlargement of part of plate III, 1. An epidote grain occurs just below the centre of the picture. Plane light. X 62.

3. Hornblende-biotite gneiss. Thin section 614-63-4. An example of a quartz-rich variety collected from close to a contact with meta-arkose. The dark minerals are biotite and hornblende. The light minerals are quartz and feldspars. Plane light. X 25.

4. Same view as Plate III, 3. Crossed nicols. X 25.

5. Amphibolite (unit 2). Thin section 614-28-11. This is a clinopyroxene-bearing (centre, left centre) variety. The light minerals are plagioclase and minor quartz. Plane light. X 25.

6. Similar view to Plate III, 5 (slightly rotated). Crossed nicols. X 25.

7. Amphibolite. Thin section 614-36-5. This picture shows part of the amphibolite near a quartz-calcite veinlet. The alteration of hornblende (dark) to an actinolitic amphibole (lighter) is probably related to this veinlet. The light minerals are plagioclase and minor quartz. Plane light. X 62.

8. Amphibolite. Thin section 624-67-9a. Consists predominately of hornblende but contains minor sericitized plagioclase and very minor quartz. Plane light. X 10.

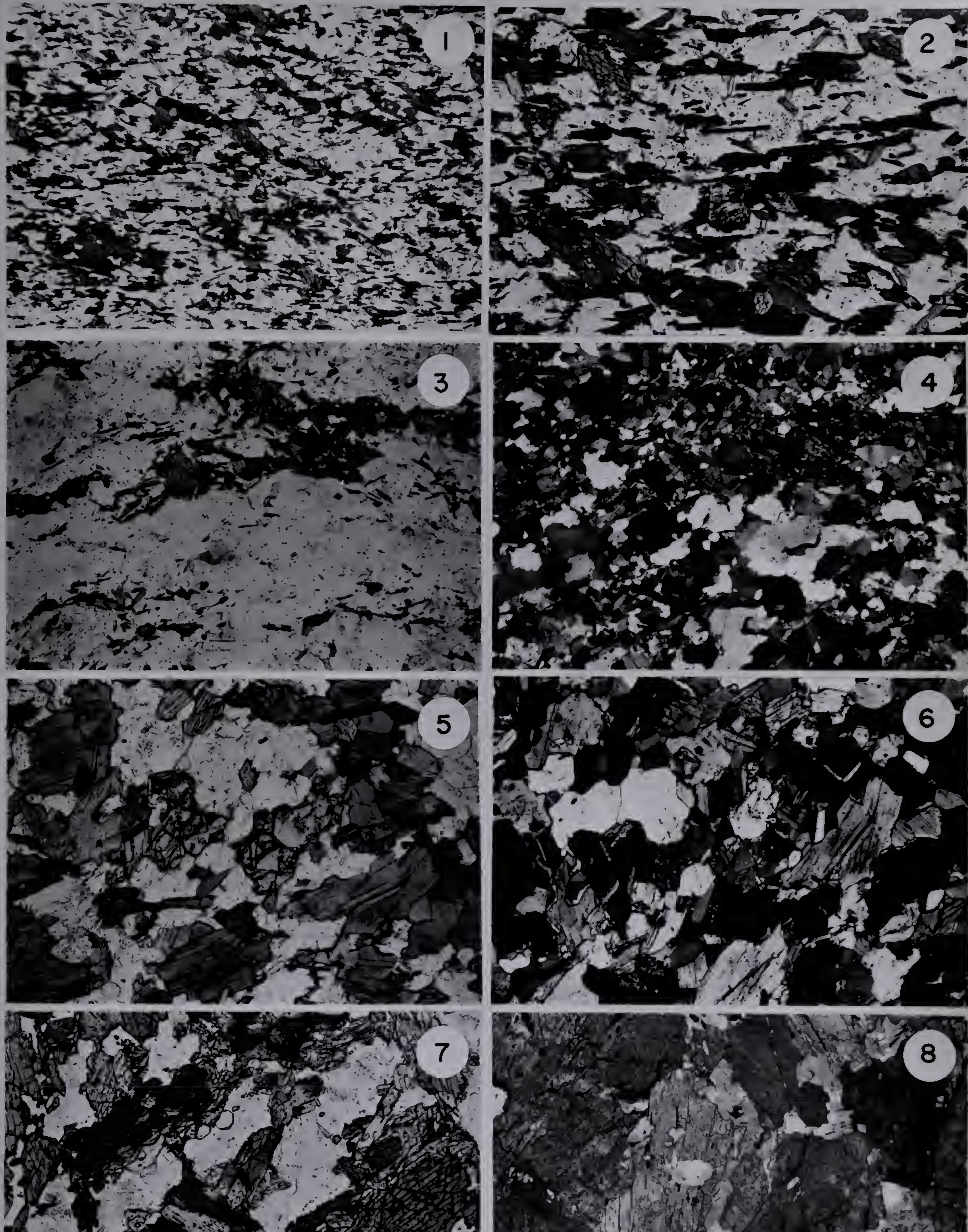
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PLATE IV

1. <u>Knobby biotite-plagioclase gneiss (sub-unit 3a)</u>. Thin section 624-81-5. An almost euhedral, cloudy plagioclase porphyroblast (centre) has triangular areas of quartz at both ends (pressure shadows?) and occurs in a matrix of fine-grained quartz, plagioclase, and biotite with flakes of coarser biotite. Plane light. X 10.

2. Same view as Plate IV, 1. Note that despite the almost euhedral appearance of the plagioclase porphyroblast (Plate IV, 1) it consists mainly of an aggregate of small grains. Two optically continuous areas within the porphyroblast occur on the upper right and lower right margins of it. Crossed nicols. X 10.

3. <u>Biotite gneiss (Sub-unit 3b)</u>. Thin section 624-56-15. Consists predominately of biotite, quartz, and plagioclase. Plane light. X 25.

4. Same view as Plate IV, 3. Crossed nicols. X 25.

5. <u>Biotite gneiss</u>. Thin section 624-56-15. Shows a microfold, outlined by biotite, with a quartzo-feldspathic core. Crossed nicols. X 25.

6. Same view as Plate IV, 5. Plane light. X 25.

7. <u>Biotite gneiss</u>. Thin section 634-52-1. Consists predominately of biotite, plagioclase, microcline, and quartz. Plane light. X 25.

8. Same view as Plate IV, 7. Crossed nicols. X 25.

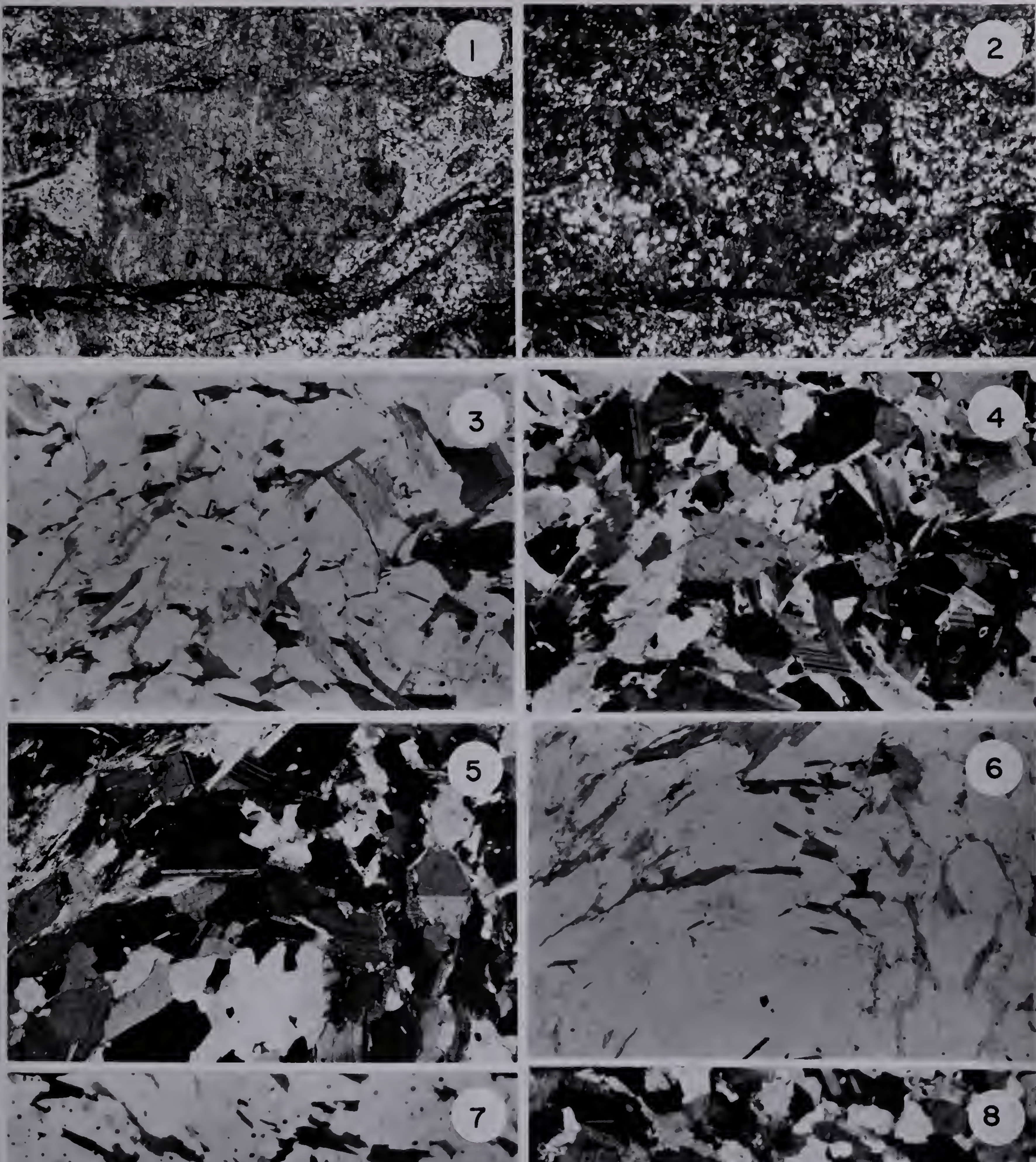
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PLATE V

1. <u>Acidic meta-volcanic (?) rock (unit 4)</u>. This is a very thinly layered variety, perhaps originally a tuff. 55° 41' 34" N, 105° 59' 35" W. Black Bear Island Lake Area (West Half). (The lens cap is 2 inches in diameter).

2. <u>Acidic meta-volcanic (?) rock</u>. Thin section 614-49-6. A tuffaceous (?) variety containing thin, biotite-rich layers. The light minerals are quartz, microcline, and plagioclase. Plane light. X 25.

3. Same as Plate V, 2. Crossed nicols. X 25.

4. <u>Acidic meta-volcanic (?) rock</u>. Thin section 624-21-5b. Consists predominantly of quartz and K-feldspar (lightly stained), with lesser slightly sericitized plagioclase and biotite. Plane light. X 62.

5. <u>Acidic meta-volcanic (?) rock</u>. Thin section 614-95-4. This is a slightly granulated variety containing abundant biotite and late opaque minerals. The large opaque grain in the upper left corner is partly rimmed by sphene. Plane light. X 25.

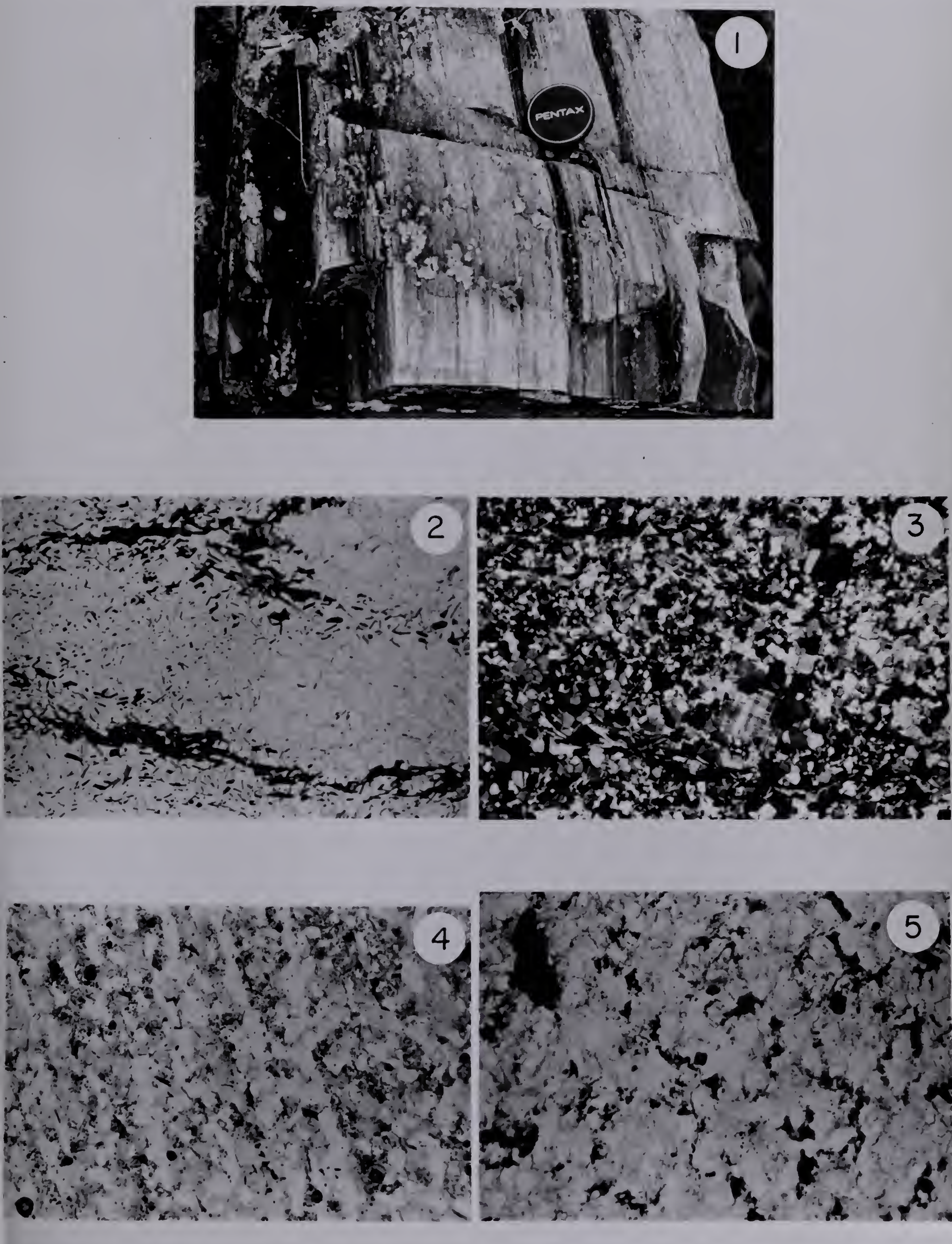
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PLATE VI

1. Biotite-cordierite-sillimanite-garnet gneiss (unit 5). Thin section 614-19-1c. A general view showing polysynthetic twinning in cordierite (right centre) and plagioclase (left centre, near centre of bottom). The other minerals are microcline, biotite and quartz. Crossed nicols. X 25.

2. Biotite-cordierite-sillimanite-garnet gneiss. Thin section 614-19-1c. A large grain of cordierite (also see Plate VI, 1) shows three sets of polysynthetic twins on (110) which are mutually at about 60°. The horizontal dark area in the upper right of this grain is a biotite flake. A grain of cordierite showing simple twinning occurs immediately right of the lower right hand side of the large cordierite grain. Crossed nicols. X 62.

3. Biotite-cordierite-sillimanite gneiss (unit 5). Thin section 614-19-8c. Shows a simple twin of cordierite with a few polysynthetic lamellae in each part. Crossed nicols. X 62.

4. Biotite-cordierite-sillimanite gneiss. Thin section 614-19-8c. Shows polysynthetic (centre of picture) and cyclic (right margin) twins in cordierite. The cordierite is surrounded by biotite, microcline, and quartz. One biotite flake cuts obliquely across a polysynthetic twin plane in cordierite (right upper centre), suggesting that the biotite formed later than the twinning. Crossed nicols. X 62.

5, 6, 7, & 8. Biotite-cordierite-sillimanite gneiss. Thin section 624-66-6b. Varieties of polysynthetic twinning in different parts of a single large porphyroblastic aggregate of cordierite. In all cases the polysynthetic lamellae are on (110) and belong to three sets which are mutually at about 60°, but local irregularities are common. The section was badly fractured during preparation, hence the numerous fractures in 7 and 8. The elongate vertical dark area in the top centre of 6 is a biotite flake. Crossed nicols. Number 7, X 25; all others, X 62.

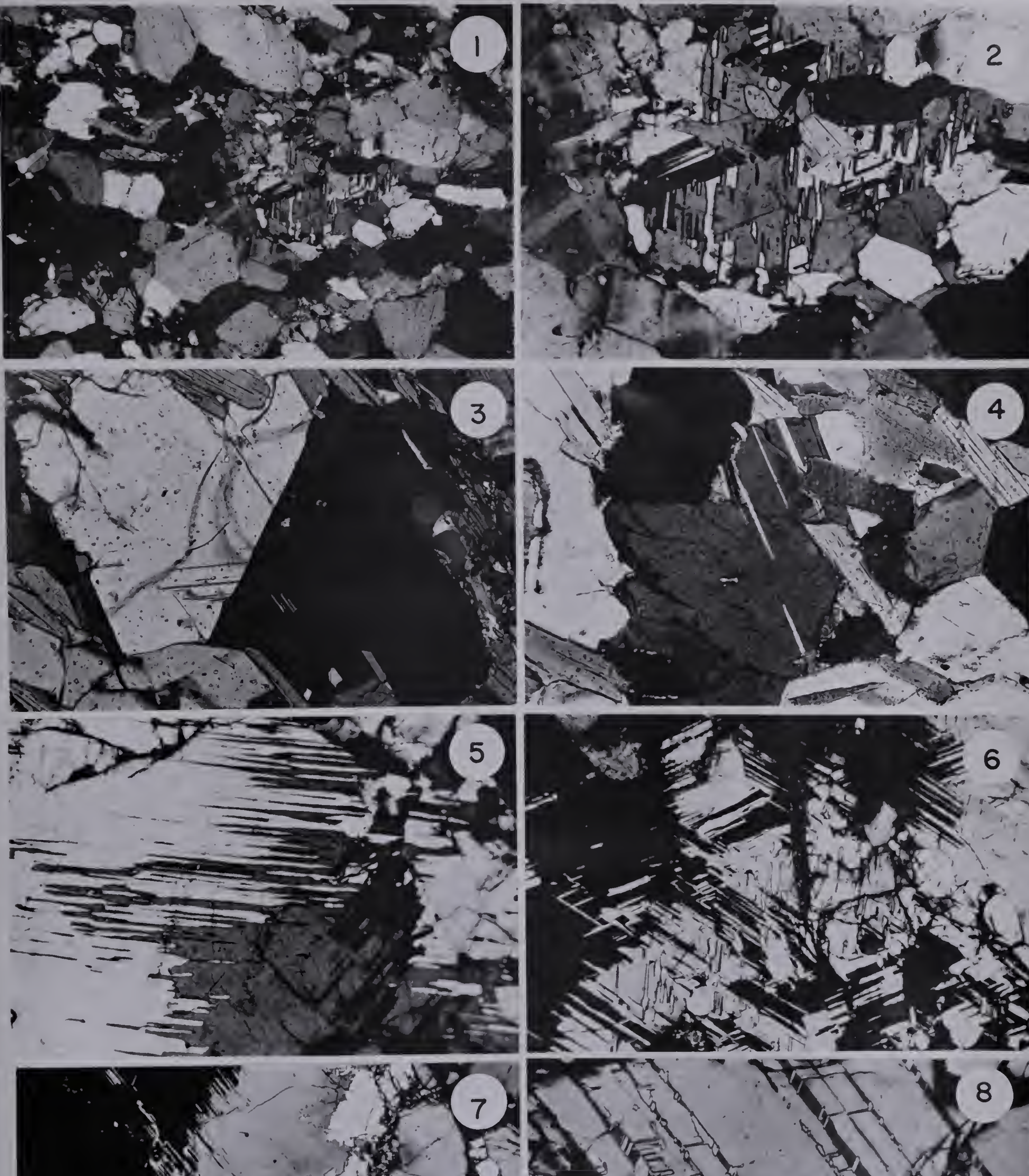
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PLATE VII

1. Biotite-cordierite-sillimanite-garnet gneiss (unit 5). Thin section 614-19-1c. A swarm of sillimanite needles occur in and seem to replace cordierite and biotite. Other light minerals (top) are microcline and quartz. Plane light. X 62.

2. Biotite-cordierite-sillimanite-garnet gneiss. Thin section 614-19-1c. Shows part of a garnet porphyroblast (high relief) with inclusions (?) and embayments of cordierite. The cordierite contains sillimanite needles and aggregates (lower right) and a few small biotite flakes. The garnet porphyroblast is separated from another porphyroblast (lower left and upper left corners) by cordierite. Plane light. X 25.

3. Biotite-cordierite-sillimanite-garnet gneiss. Thin section 624-Y-7. A garnet-rich part of a garnet-rich variety. Contains interstitial biotite and minor quartz (bottom right). Plane light. X 10.

4. Same thin section as Plate VII, 3. A large area of cordierite (centre, upper left, lower left) shows incipient alteration (cloudiness) along fractures and contains small biotite flakes and some porphyroblastic garnet. Upper right similar to plate VII, 3. Plane light. X 10.

5. Biotite-sillimanite-garnet gneiss. Thin section 614-19-7. This is a quartzo-feldspathic variety. The minerals are quartz, microcline, and biotite. Plane light. X 25.

6. Same view as Plate VII, 5. Crossed nicols. X 25.

7. Plagioclase-scapolite-clinopyroxene rock. Thin section 634-98-8. Shows part of a poikiloblastic plagioclase grain containing euhedral diopside (in part plucked out during thin section preparation). Crossed nicols. X 25.

8. Plagioclase-scapolite-clinopyroxene rock. Thin section 634-98-8. Diopside and sphene (lower left centre) occur in scapolite. Plane light. X 25.

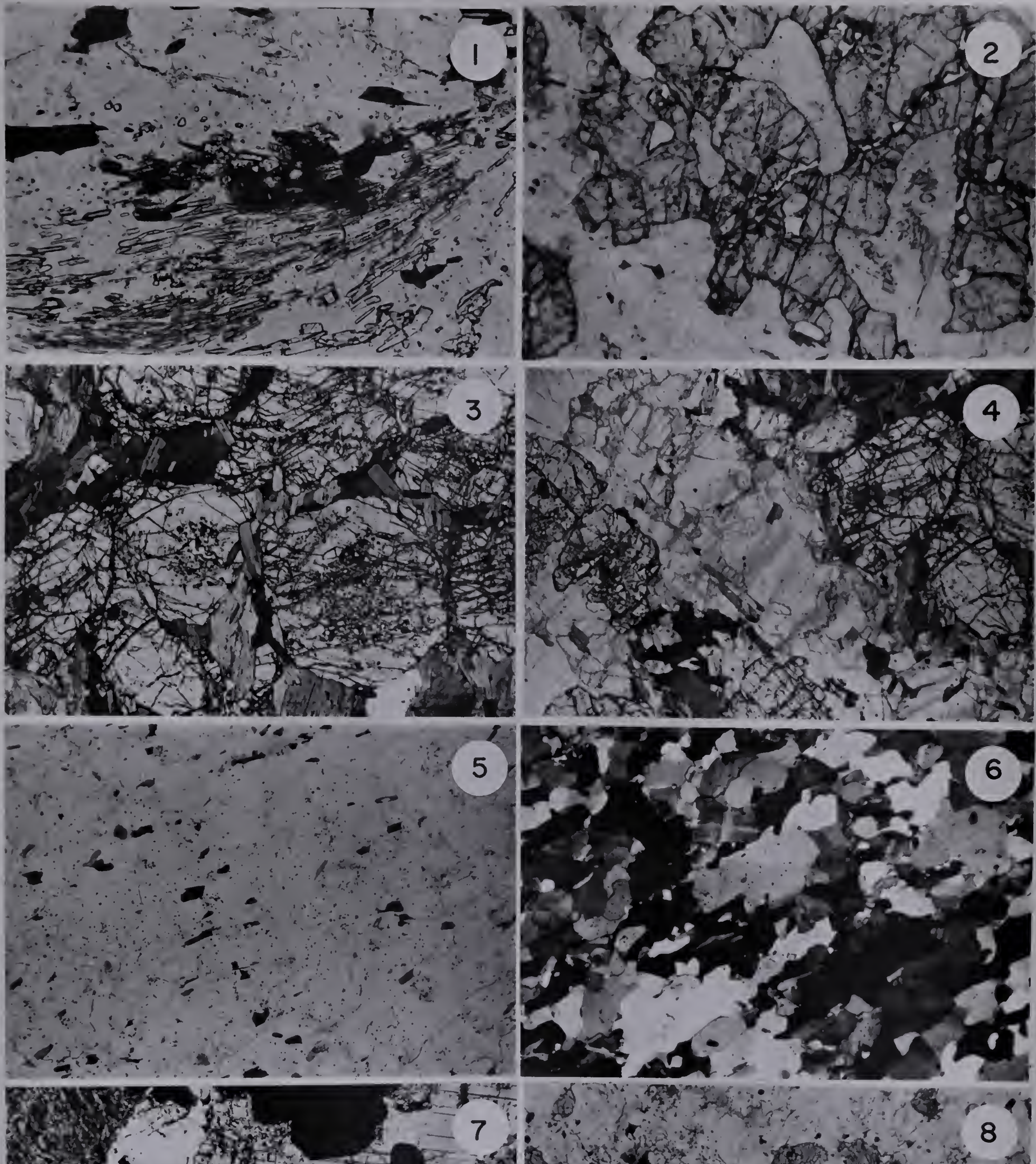
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PLATE VIII

1. Hypersthene amphibolite (sub-unit 6a). Thin section 614-89-4. Shows hypersthene (lower centre) and hornblende (upper centre) in plagioclase and minor quartz. Plane light. X 25.

2. Similar view to Plat VII, 1. (slightly rotated). Note the albite twinning in the plagioclase. Crossed nicols. X 25.

3. Hypersthene amphibolite. Thin section 614-89-4. Shows large, poikiloblastic hornblende grains and lesser plagioclase, hypersthene (right centre), and quartz. Plane light. X 10.

4. Clinopyroxene amphibolite (sub-unit 6b). Thin section 624-Y-3. The grains which appear to have a higher relief are clinopyroxene, the rest are hornblende. The small light areas are holes in the section. Plane light. X 25.

5. Quartz-pebble meta-conglomerate (unit 7). Thin section 614-30-4. The elongate areas of large, sutured grains are part of stretched pebbles of quartz. The finer material is the matrix and consists of muscovite, quartz, and minor K-feldspar. Crossed nicols. X 10.

6. Quartz-pebble meta-conglomerate. Thin section 614-30-4. Similar to Plate VIII, 5. The pebbles are separated, in most cases by thin films of muscovite only. Crossed nicols. X 10.

7. Quartz-pebble-meta-conglomerate. Thin section 614-30-4. Parts of two quartz pebbles are separated by a biotite-rich matrix (nearly vertical, centre of photograph). This is from the least deformed outcrop of meta-conglomerate. Crossed nicols. X 10.

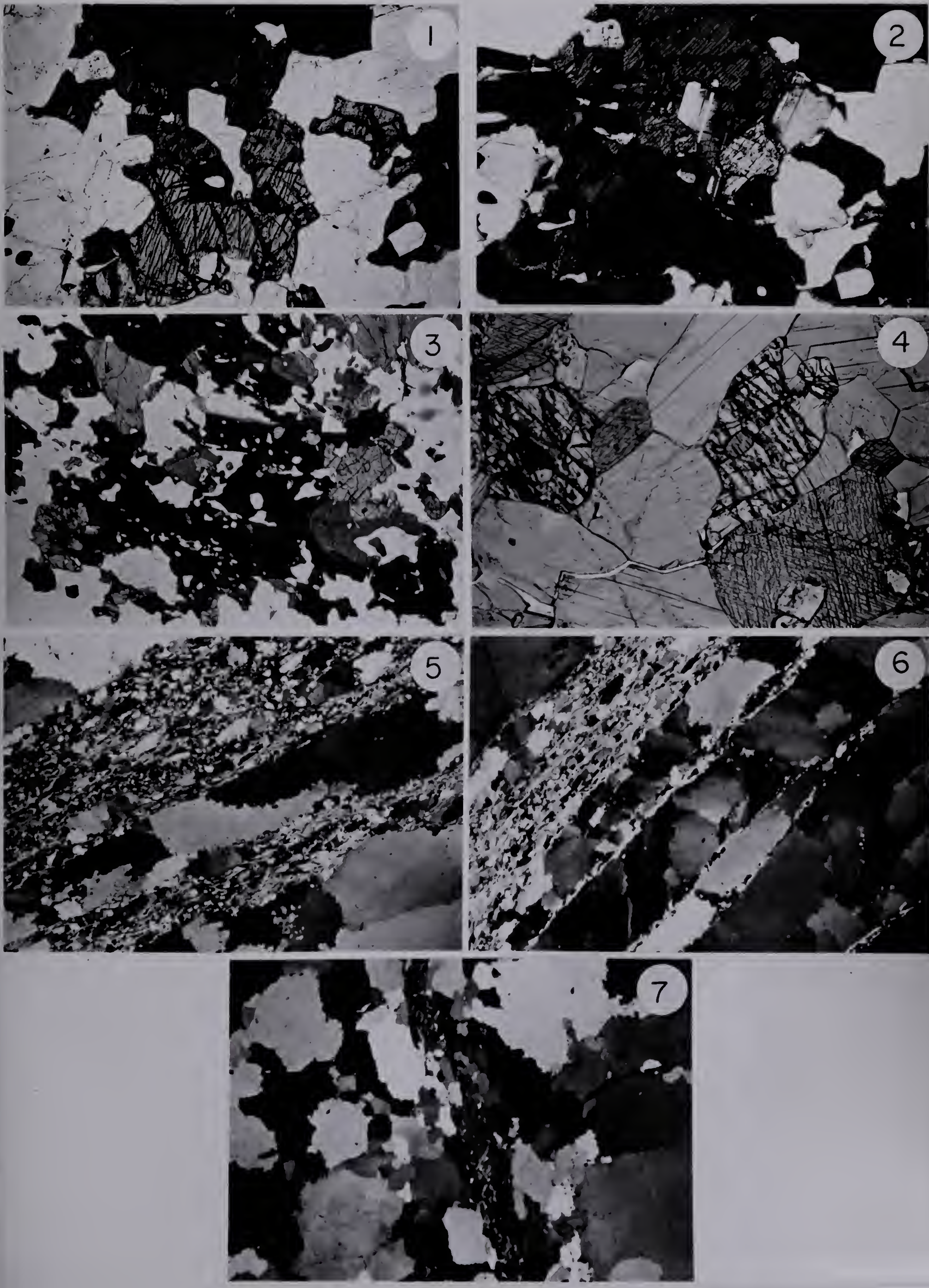
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PLATE IX

1. <u>Quartz-pebble meta-conglomerate (unit 7)</u>. A moderately stretched variety of muscovitic, feldspathic meta-conglomerate. West side of Orr Lake, (55° 49' 53" N, 105° 54' 05" W), Eulas Lake Area (West Half). (The lens cap is 2 inches in diameter).

2. <u>Quartz-pebble meta-conglomerate (unit 8)</u>. A strongly stretched calcareous (actinolitic) variety. The pebbles are distinguishable from the matrix on the weathered surface because lichen grows only on the matrix. On the fresh surface (spalled area, bottom centre) the outlines of the pebbles cannot be discerned. 55° 38' 12" N, 106° 02' 37" W. Sandfly Lake Area (East Half).

3. <u>Quartz-pebble meta-conglomerate (unit 7)</u>. Stretched and folded pebbles are illustrated. 55° 41' 23" N, 106° 01' 28" W. Sandfly Lake Area (East Half).


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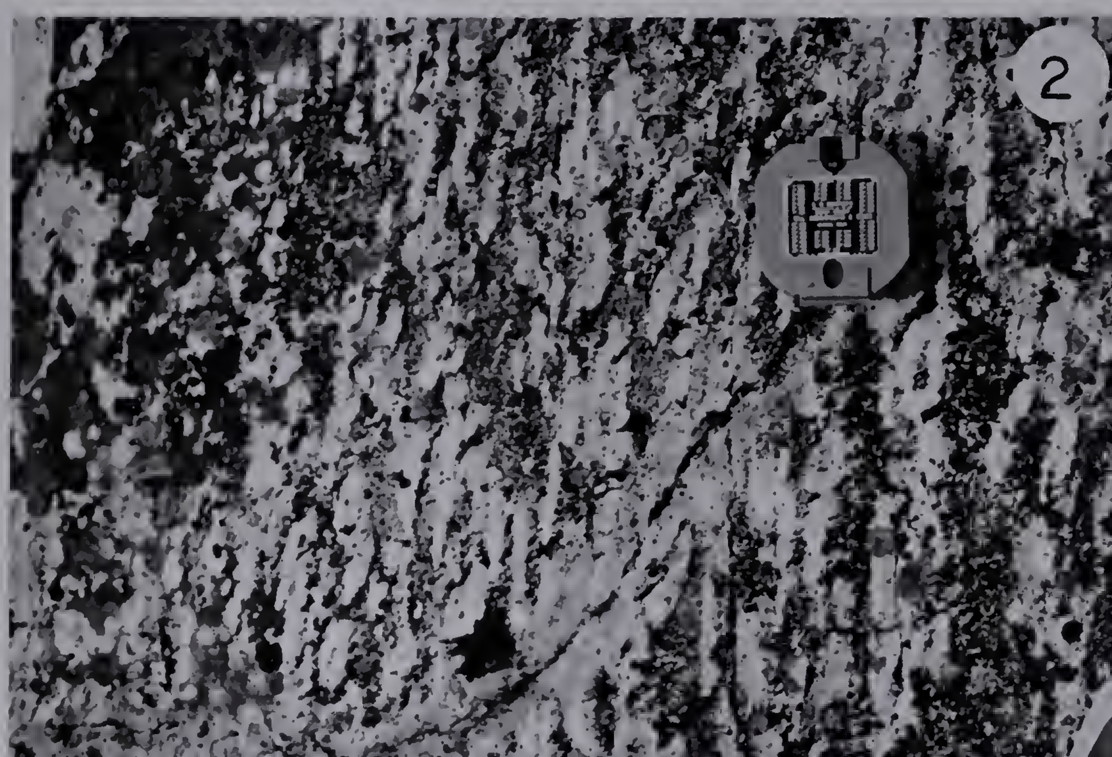
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PLATE X

1. Quartzite (unit 8). Unusually well preserved bedding is shown (indicated by parting along micaceous films and by weak colour-layering). 55° 48' 56" N, 105° 56' 34" W. Eulas Lake Area (West Half).

2. Quartzite (unit 8). Well preserved cross bedding in a comparatively undeformed outcrop of quartzite. "Tops" are towards the top of the photograph. The quartzite is intruded by a pegmatite stringer (right side of photograph). Southeast corner of Duddridge Lake (55° 30' 59" N, 106° 11' 02" W), Sandfly Lake Area (East Half).

3. Interbedded quartzite (massive appearance) and biotite-muscovite-quartz schist. Foliation in the schist is not parallel to the bedding and may be axial plane foliation. South side of Lanes Lake (55° 49' 45" N, 105° 55' 47" W), Eulas Lake Area (West Half). (The lens cap is 2 inches in diameter).


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PLATE XI

1. "Pure" quartzite (unit 8). Thin section 614-46-6. Predominately quartz, but the section contains minor microcline (left centre), and muscovite (upper right). Crossed nicols. X 25.

2. "Pure" quartzite. Thin section 614-38-11. Consists entirely of quartz apart from a fine dusting of opaque minerals and a few muscovite flakes. Crossed nicols. X 25.

3. Feldspathic quartzite (unit 8). Thin section 614-22-19a. Consists of quartz, K-feldspar (very slightly cloudy), and muscovite. Crossed nicols. X 25.

4. Calcareous quartzite (unit 8). Thin section 614-38-5. Ovoid areas of quartz (original grains?) are outlined by actinolite, opaque minerals, and epidote. Plane light. X 25.

5. Calcareous quartzite. Thin section 614-40-10. Consists of quartz, microcline, actinolite, and diopside (upper right, above left centre). Plane light. X 25.

6. Same view as Plate XI, 5. Crossed nicols. X 25.

7. Calcareous quartzite. Thin section 614-40-10. Shows a remarkable development of elongate actinolite porphyroblasts (with sieve texture) in a matrix consisting predominately of quartz and microcline. Minor opaque minerals. Plane light. X 25.

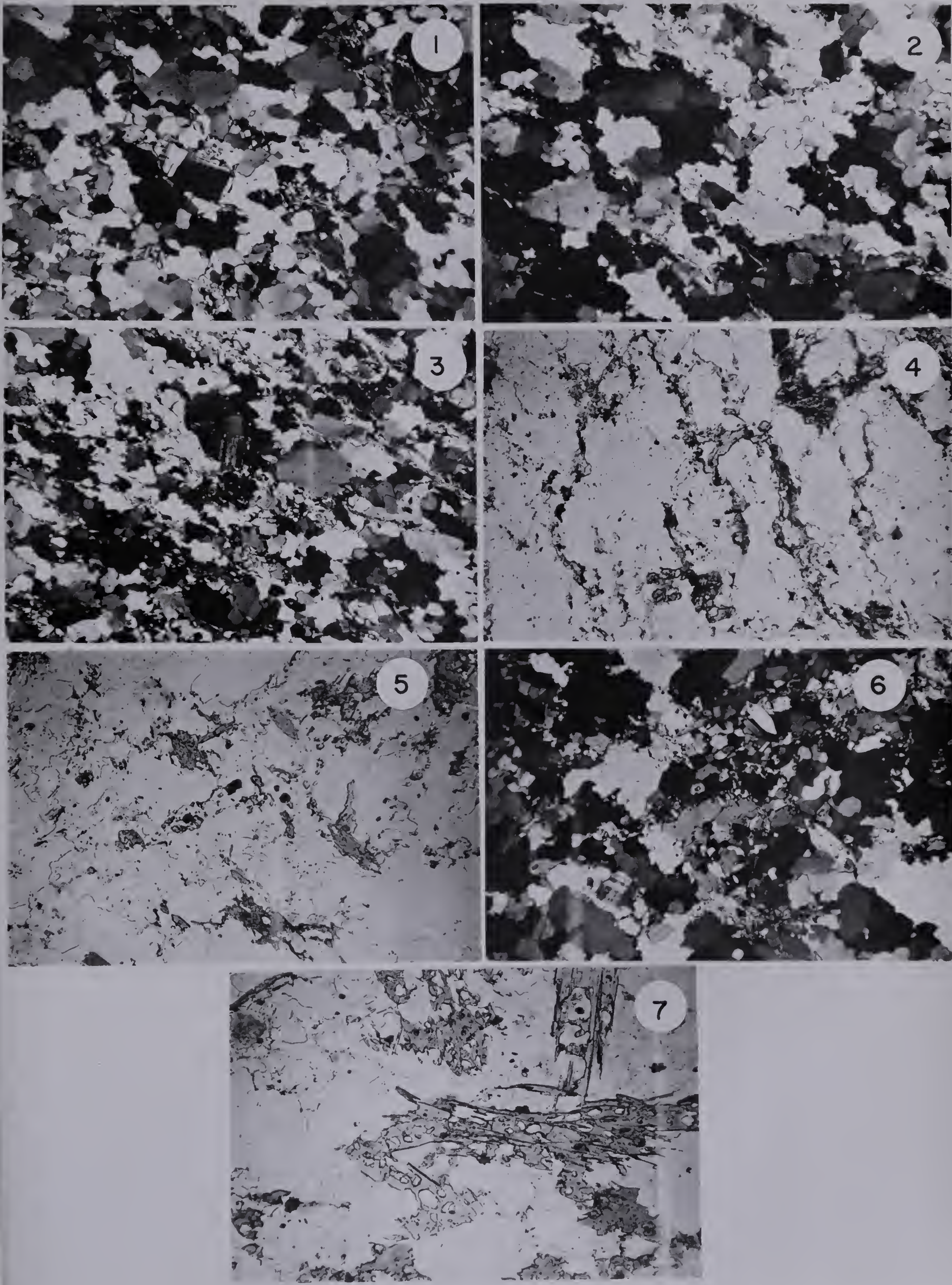
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PLATE XII

1. <u>Biotite-muscovite-quartz schist (unit 9)</u>. Thin section 614-25-7. A typical example of this rock type showing interlayering of biotite and muscovite. Plane light. X 62.

2. <u>Biotite-muscovite-quartz schist</u>. Thin section 614-23-8b. A muscovite-rich variety showing microfolding. Plane light. X 25.

3. <u>Biotite-muscovite-quartz schist</u>. Thin section 614-23-8b. A tourmaline grain occurs in the centre of the picture. Plane light. X 62.

4. <u>Biotite-muscovite-quartz-andulusite schist (unit 9)</u>. Thin section 614-46-9. Shows a rotated andalusite porphyroblast (upper centre) with an area of quartz, containing a cluster of fibrolite needles, below. Other minerals are biotite and muscovite. Plane light. X 10.

5. Same thin section as Plate XII, 4. Shows the cluster of fibrolite needles and part of the andalusite porphyroblast. Opaque and quartz inclusions occur in the porphyroblast. Plane light. X 25.

6. <u>Biotite-muscovite-quartz-andalusite schist</u>. Thin section 614-46-9. An andalusite grain (centre) with pronounced sieve texture has replaced biotite in a microfold. Plane light. X 25.

7. <u>Biotite-muscovite-quartz-andalusite schist</u>. Thin section 614-46-9. Andalusite has replaced biotite. There is a film of opaque minerals along the left margin of the large andalusite porphyroblast in the left centre of the picture, and inclusions of opaque minerals, quartz, and biotite occur within this porphyroblast. Plane light. X 25.

8. <u>Biotite-muscovite-quartz-andalusite schist</u>. Thin section 614-46-9. A microfold is outlined by biotite and andalusite. Plane light. X 25.

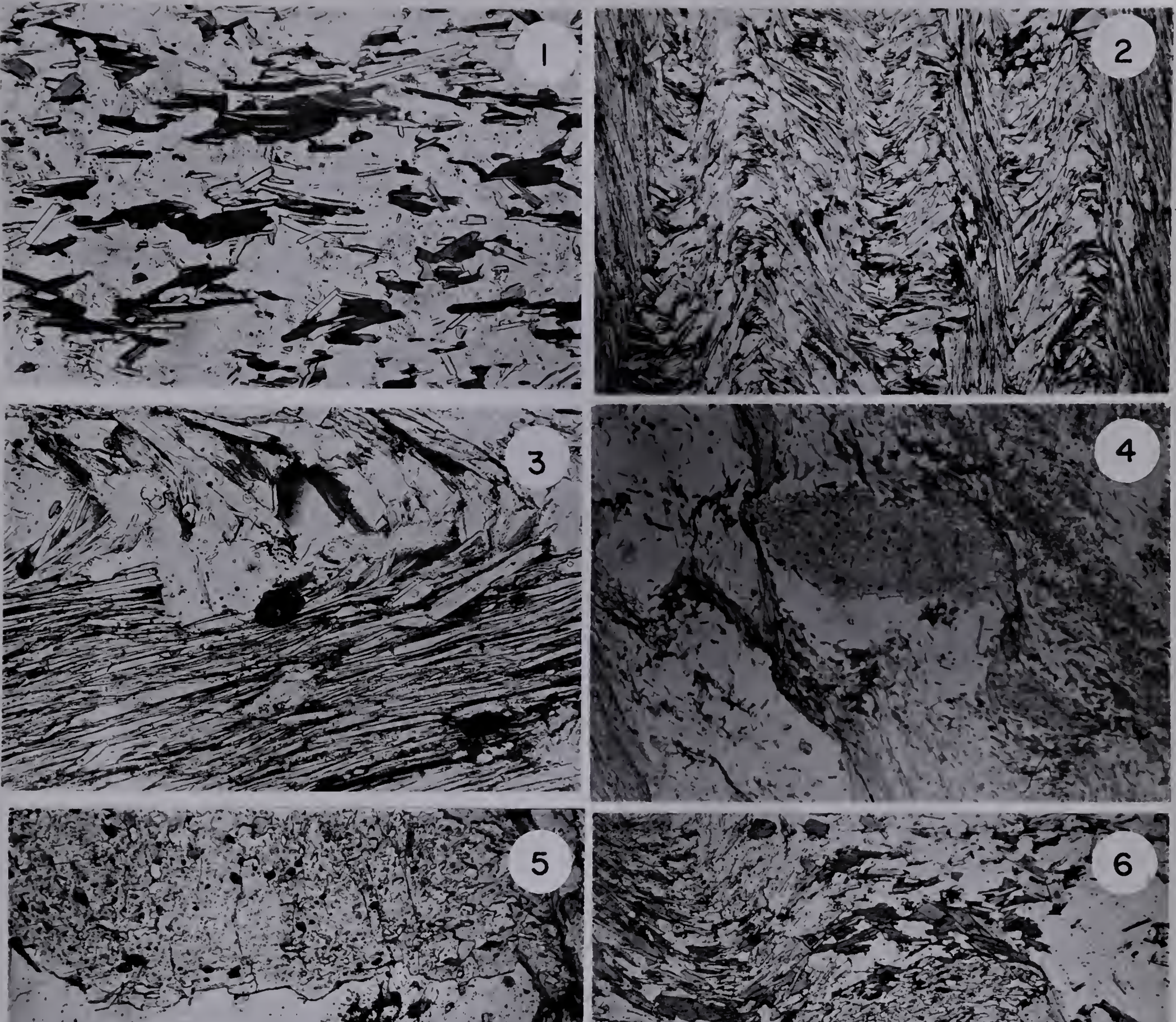
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PLATE XIII

1. <u>Epidiorite (unit 10)</u>. The dark, fine-grained patches are inclusions of hornblende-biotite gneiss (unit 2). 55° 42' 49" N, 106° 01' 55" W. Sandfly Lake Area (East Half).

2. <u>Epidiorite</u>. This photograph shows the fresh, coarse-grained, igneous appearance of some of the epidiorite in the field. Compare this with the appearance in thin section (Plate XIV). 55° 49' 48" N, 105° 55' 27" W. Eulas Lake Area (West Half).


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PLATE XIV

1. <u>Epidiorite (unit 10)</u>. Thin section 614-27-1. The dark minerals are aggregates of hornblende grains with pronounced sieve texture, minor biotite, and minor opaque minerals. The light areas are mainly plagioclase with very minor quartz. The plagioclase is in part fairly coarse and may be the original igneous plagioclase. Plane light. X 10.

2. Same view as Plate XIV, 1. Crossed nicols. X 10.

3. <u>Epidiorite</u>. Thin section 614-70-5b. The dark minerals are predominantly aggregates of fine, metamorphic hornblende, with minor biotite. Slightly coarser biotite replaces hornblende (lower left). The light minerals are an aggregate of fine, metamorphic plagioclase and minor quartz. Plane light. X 10.

4. Same view as Place XIV, 3. Crossed nicols. X 10.

5. <u>Epidiorite</u>. Thin section 614-27-1. Shows a large sieve texture hornblende grain (containing a few biotite flakes and minor opaque minerals). Light minerals are in part probably original igneous plagioclase and in part metamorphic plagioclase. Minor quartz. Plane light. X 10.

6. <u>Epidiorite</u>. Thin section 614-27-1 (partly overlaps Plate XIV, 5). Note the bent and fractured plagioclase grains in the centre. Crossed nicols. X 10.

7. <u>Epidiorite</u>. Thin section 614-70-5b. Shows an aggregate of metamorphic hornblende, biotite, and sphene. Plane light. X 25.

8. <u>Epidiorite</u>. Thin section 614-27-1. Shows one of the bent and fractured, probably igneous, plagioclase grains in Plate XIV, 6. Crossed nicols. X 25.

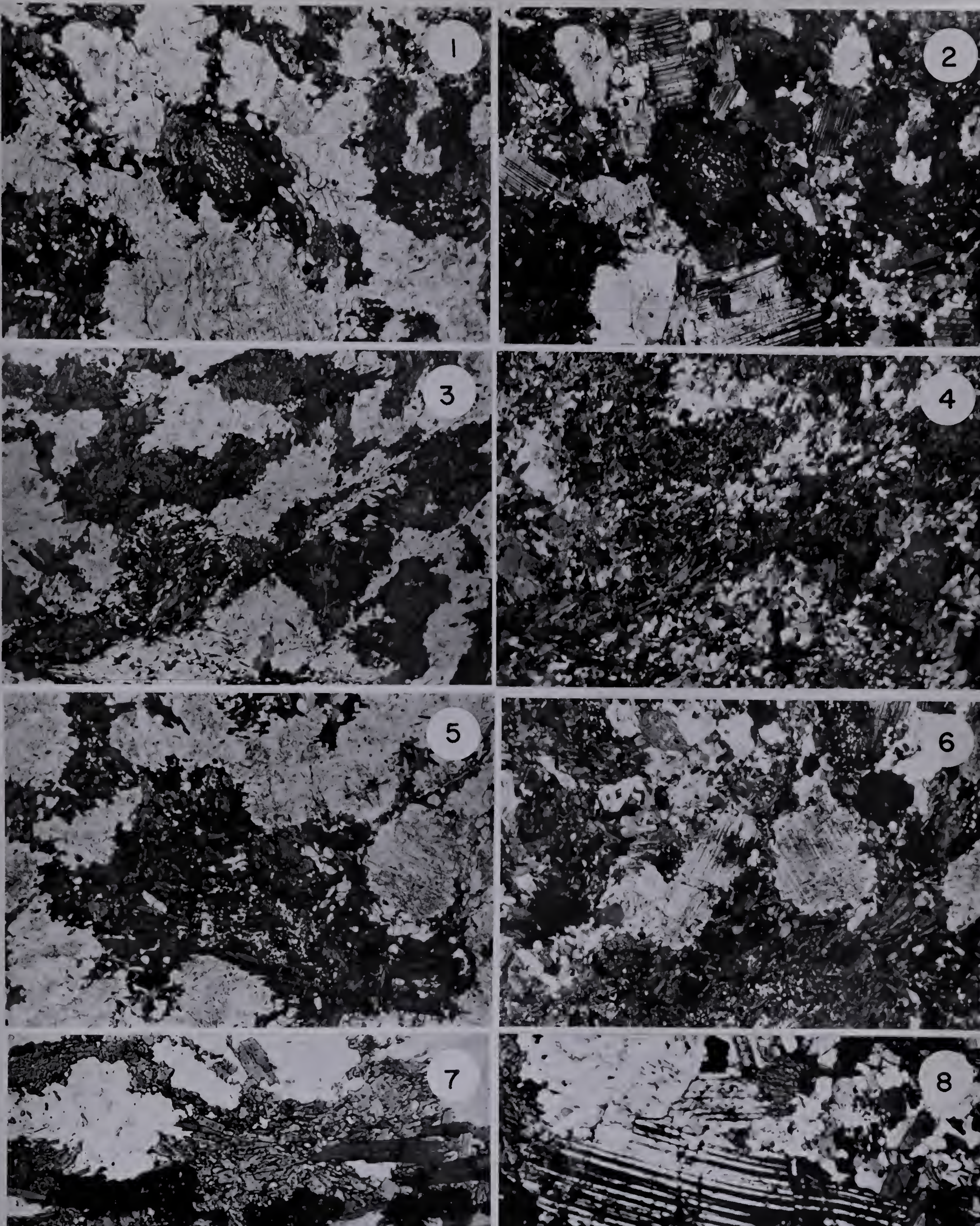
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PLATE XV

1. Anthophyllite-cordierite-biotite gneiss. Thin section 614-39-6. Anthophyllite (centre, nearly vertical) transects biotite (with dark pleochroic haloes around zircon), plagioclase, and quartz. Plane light. X 25.

2. Anthophyllite-cordierite-biotite gneiss. Thin section 614-39-6. A cordierite porphyroblast (slightly cloudy, lower centre) is partly altered to chlorite (left margin, pleochroic haloes) and transected by porphyroblastic anthophyllite (top of cordierite grain). A subhedral plagioclase porphyroblast with numerous biotite inclusions occurs on the left margin below the centre. Biotite occurs above and below this. At the bottom of the photograph there is a mosaic (typical matrix) of biotite, quartz, and plagioclase. Plane light. X 25.

3. Anthophyllite-cordierite-biotite gneiss. Thin section 614-39-6. Shows part of a large cordierite porphyroblast which is partly altered to laths of sericite and to chlorite. Plane light. X 62.

4. Augen gneiss (unit 11). Thin section 614-38-9. Shows a moderately granulated, perthitic K-feldspar porphyroblast in a matrix of quartz, K-feldspar, plagioclase, and biotite. Crossed nicols. X 10.

5. Augen gneiss. Shows the typical appearance in the field. The elongate pale areas are pink porphyroblasts of K-feldspar. 55° 42' 59" N, 106° 03' 47" W. Sandfly Lake Area (East Half).

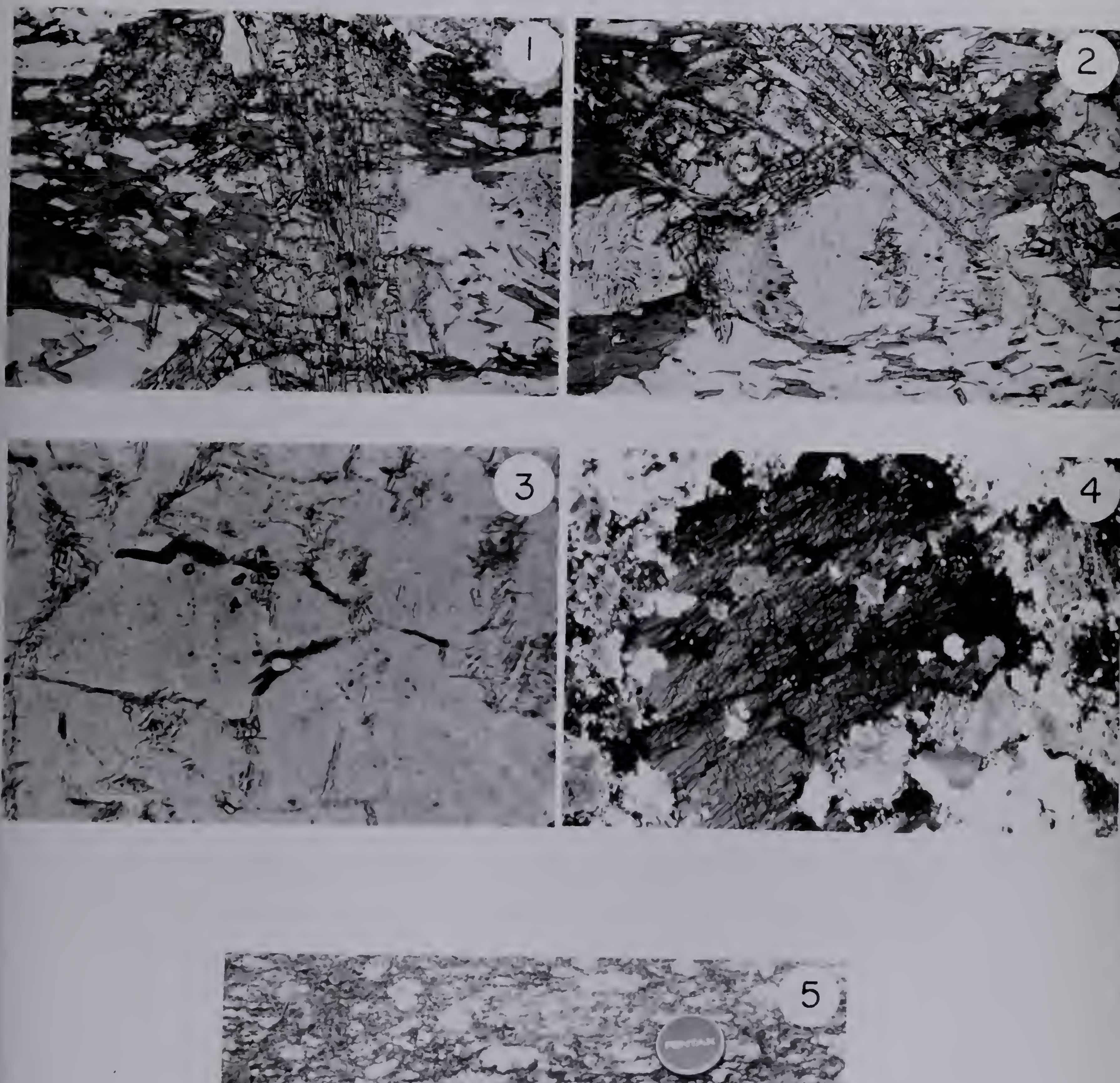
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PLATE XVI

1. <u>Porphyroblastic potassium feldspar gneiss (unit 11)</u>. The large, angular porphyroblasts consist of pink potassium feldspar. The matrix is greyish and consists of biotite, hornblende, plagioclase, potassium feldspar, and quartz. 55° 40' 25" N, 106° 02' 34" W. Sandfly Lake Area (East Half). (The lens cap is 2 inches in diameter).

2. <u>Porphyroblastic potassium feldspar gneiss</u>. Same outcrop as the preceding photograph. The rock in the centre of the picture is an inclusion consisting predominantly of plagioclase, biotite, and hornblende. It may have been epidiorite (unit 10) previously.

3. <u>Agmatite (unit 11)</u>. The dark-coloured rock is hypersthene amphibolite (unit 6a). The light-coloured rock which seems to have been intruded into the amphibolite predominantly along joints is part of the eastern granitic rocks (unit 13). 55° 47' 07" N, 105° 48' 25" W. Eulas Lake Area (West Half).

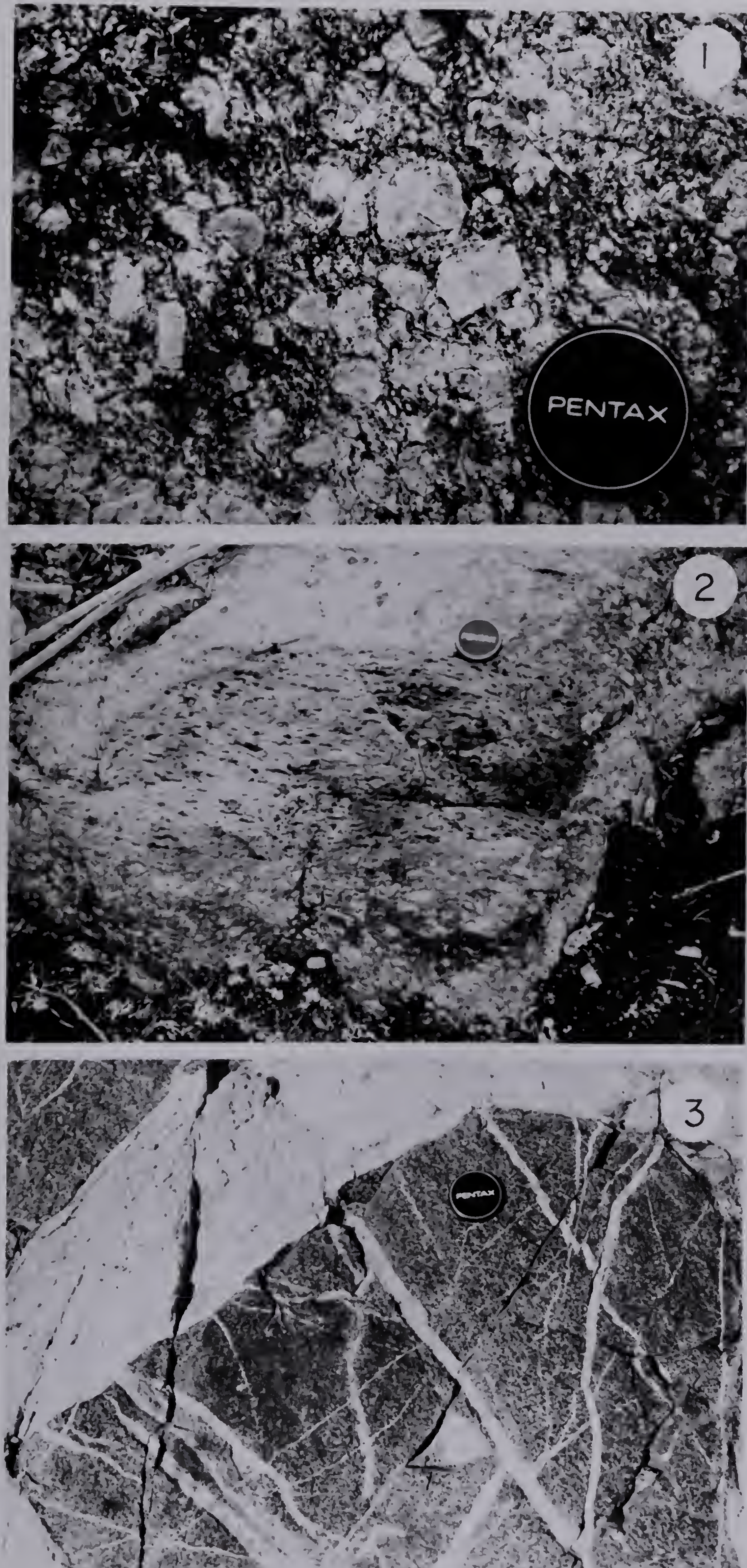
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PLATE XVII

1. Migmatite (unit 11). The quartzo-feldspathic component has been mobilized and is intrusive into the more mafic component (biotite gneiss, unit 3b). 55° 30' 16" N, 105° 49' 27"W. Black Bear Island Lake Area (West Half).

2. Migmatite. The quartzo-feldspathic component is locally discordant and intrusive into the more mafic component but in general is concordant. This variety is intermediate between that shown in Plate XVII, 1 and that shown in Plate XVII, 3. 55° 30' 46" N, 105° 45' 23" W. Black Bear Island Lake Area (West Half).

3. "Lit-par-lit" gneiss (unit 11). The quartzo-feldspathic and more mafic component are conformable. The thicker quartzo-feldspathic layers are equigranular, non-foliate, and slightly coarser-grained than most of the rock. They may have been mobilized and introduced along bedding or foliation planes. Such an origin for all of the very thin quartzo-feldspathic layers is unlikely; at least some of these are probably due to metamorphic segregation. The "lit-par-lit" gneiss and the migmatite shown in the preceding photographs are gradational into each other. Relationships such as these show the difficulty in making classifications of migmatite and determining the nature of the quartzo-feldspathic component. 55° 30' 46" N, 105° 45' 23" W. Black Bear Island Lake Area (West Half).


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PLATE XVIII

1. <u>Migmatite (unit 11)</u>. The quartzo-feldspathic component is in general concordant but locally discordant. The relative amounts of the two components (the mafic component is hornblende-biotite gneiss, unit 2) suggests intrusion of much of the quartzo-feldspathic component. 55° 44' 00" N, 106° 03' 38" W. Sandfly Lake Area (East Half).

2. <u>Migmatite</u>. Layers of amphibolite and a pale grey quartzo-feldspathic rock of uncertain origin occur in complex flow folds. Pegmatitic segregations (white) occur and are discordant locally. Elsewhere in the outcrop (not shown) there are sills of a fine-grained pink granitic rock which is probably related to the western granitic rocks (unit 12). 55° 40' 26" N, 106° 06' 05" W. Sandfly Lake Area (East Half).

3. <u>Migmatite</u>. The mafic component is hornblende-biotite gneiss (unit 2). Most of the quartzo-feldspathic component is concordant, in a general way, with the weak foliation of the gneiss, but some is markedly discordant. At the bottom and top left of the photograph there are areas in which the quartz-feldspathic component appears to have either "soaked into" the mafic component or to have only partly separated from it. 55° 42' 54" N, 106° 02' 18" W. Sandfly Lake Area (East Half).

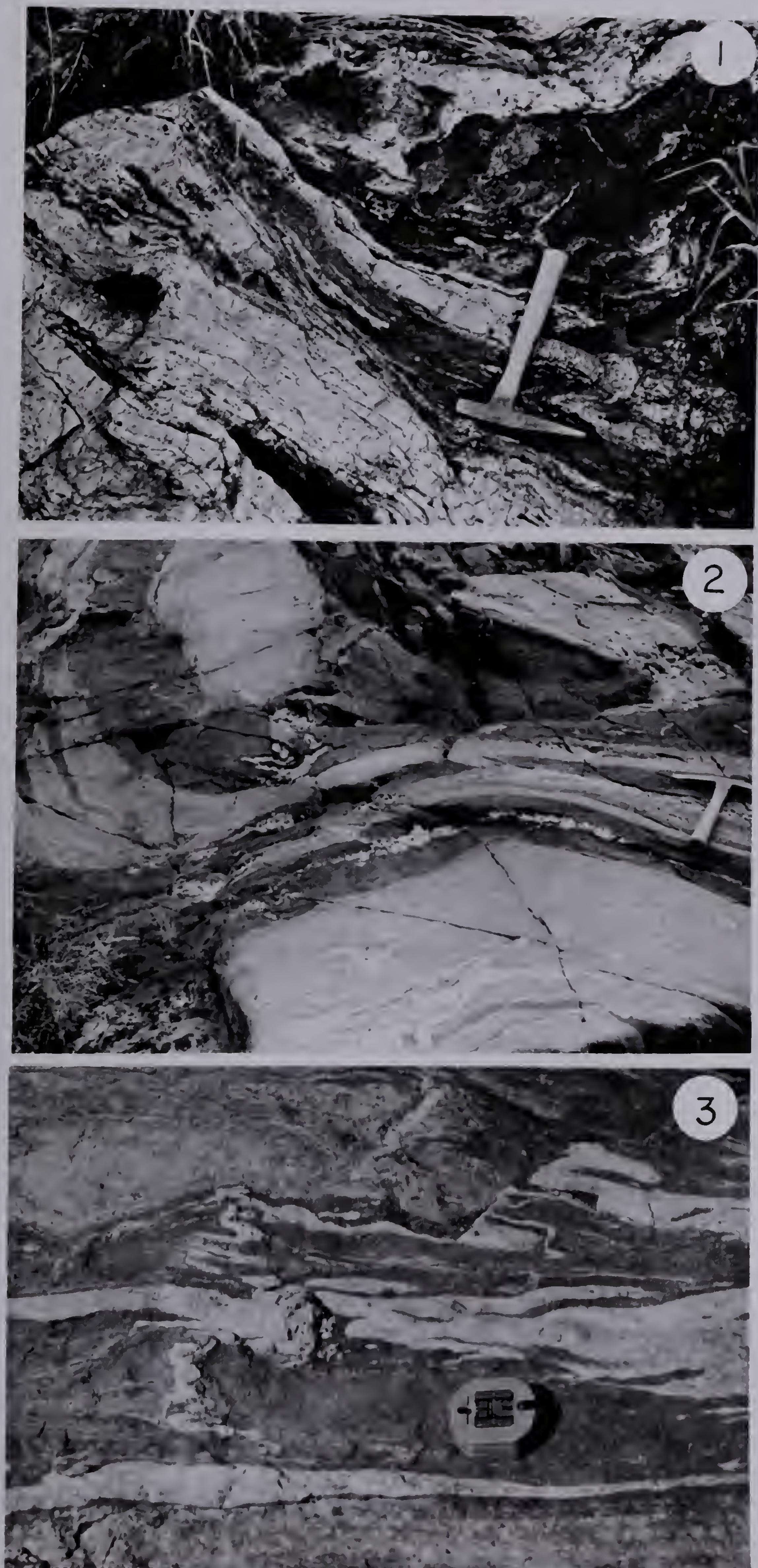
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PLATE XIX

1 & 2. Quartz monzonite (belonging to the western granitic rocks, unit 12). Thin section 614-28-6. A typical example of the rocks forming this unit. Predominantly granulated quartz, microcline, and plagioclase, minor biotite and hornblende. Crossed nicols. X 10.

3. Monzonite (Western granitic rocks). Thin section 624-97-3b. The large area of microcline (centre) may be the remnants of an original grain. Crossed nicols. X 10.

4. Quartz monzonite (Western granitic rocks). Thin section 614-22-9. The large quartz aggregate (most of right half of picture) may be the remnants of an original grain. Crossed nicols. X 10.

5. Biotite quartz diorite (Eastern granitic rocks, unit 13). Thin section 614-84-4. Predominantly plagioclase and quartz but minor biotite. The plagioclase has slightly bent twin lamellae and the quartz is sutured, but this rock has obviously not undergone the intense granulation which has affected the western granitic rocks. Crossed nicols. X 10.

6. Porphyritic or porphyroblastic granodiorite (Eastern granitic rocks). Thin section 634-89-15. Shows part of a Carlsbad-twinned, slightly perthitic megacryst of microcline (lower two-thirds of picture) and the irregular contact between it and biotite, hornblende, plagioclase, and quartz. Crossed nicols. X 10.

7. Biotite quartz diorite (Eastern granitic rocks). Thin section 614-85-1. Shows an unusually large clump of mafic and accessory minerals (see Plate XIX, 8). Plane light. X 10.

8. Biotite quartz diorite (Eastern granitic rocks). Thin section 614-85-1. Shows part of the clump in Plate XIX, 7. Note sphene (very dark, high relief, lower right), apatite (upper centre), epidote (medium dark, high relief, lower and left centre), hornblende (left margin just below middle), and biotite. Plane light. X 25.

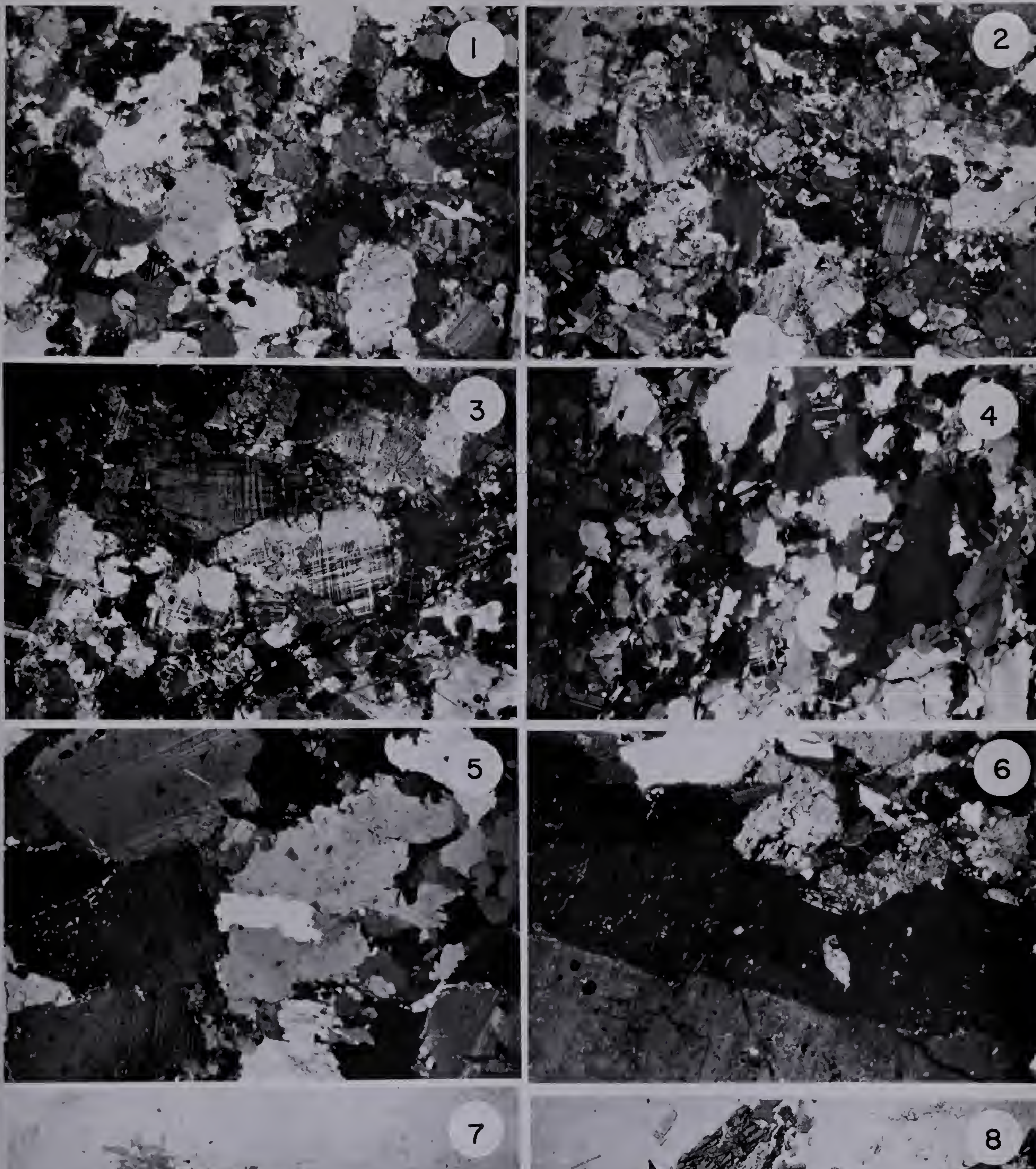
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PLATE XX

1. Eastern granitic rocks (unit 13). Unusually strongly foliated eastern granitic rocks contain rotated inclusions of amphibolite (unit 2). 55° 45' 36" N, 105° 50' 55" W. Eulas Lake Area (West Half).

2. Pegmatite (unit 14). This pegmatite is a white, K-feldspar-rich, tourmaline-bearing variety. It shows chilled margins (note very small tourmaline crystals) about one-half inch wide against a granitoid rock. 55° 42' 44" N, 106° 01' 13" W. Sandfly Lake Area (East Half). (The lens cap is 2 inches in diameter).

3. Pegmatite. This is an example of the porphyritic type. Three K-feldspar crystals are outlined with white paint. Note the irregularity of the crystal boundaries, which suggests some resorption of the crystals. 55° 43' 31" N, 106° 04' 46" W. Sandfly Lake Area (East Half).


1


2
PENTAX


3

PLATE XXI

1, 2, 3, & 4. Vein quartz (unit 15). Shows varying degrees of granulation. 1 and 2, thin section 624-67-7; 3, thin section 624-70-6; 4, thin section 624-97-14. All taken with crossed nicols. X 25.

5 & 6. Sillimanite-muscovite-magnetite schist. This occurs as an inclusion in the giant quartz vein west of Pipikos Bay, Sandfly Lake. Some of the sillimanite shows euhedral cross-sections and it all appears to replace muscovite. The magnetite fills fractures in the sillimanite and hence is the latest mineral. Plane light. X 25.

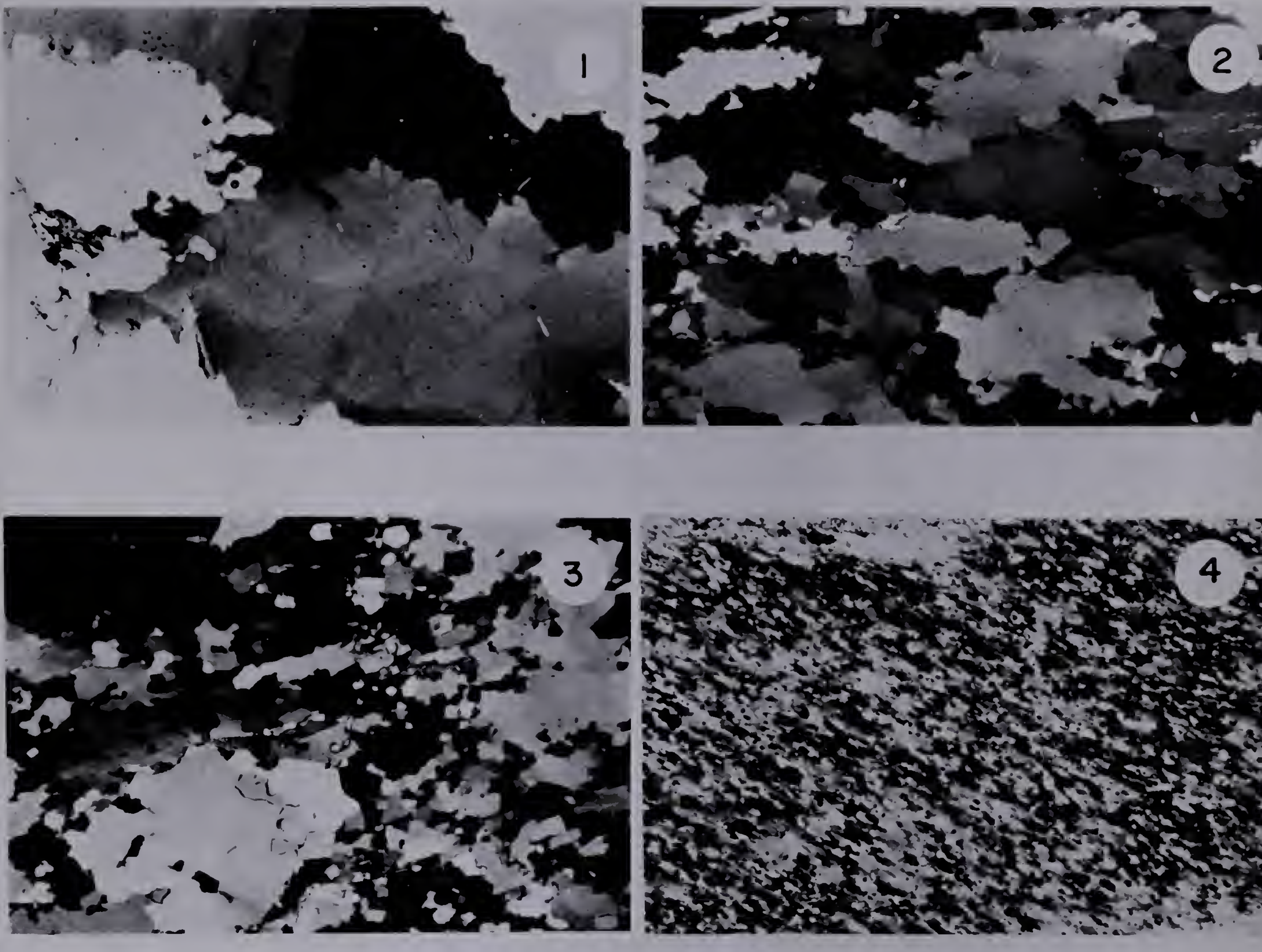
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PLATE XXII

1. Quartzite (unit 8). Shows a shallow, open, doubly plunging minor syncline. 55° 43' 45" N, 106° 02' 23" W. Sandfly Lake Area (East Half).

2. Quartzite. Shows an almost vertically plunging minor fold. 55° 40' 41" N, 106° 02' 59" W. Sandfly Lake Area (East Half).

3. Quartzite. Shows minor folds in quartzite with some interlayered biotite-muscovite-quartz schist (unit 9). Some flow has probably occurred. This photograph, the two preceding photographs, and the following photograph (Plate XXIII, 1) illustrate the wide variation in folding style which occurs in a fairly small area. 55° 40' 36" N, 106° 02' 48" W. Sandfly Lake Area (East Half).

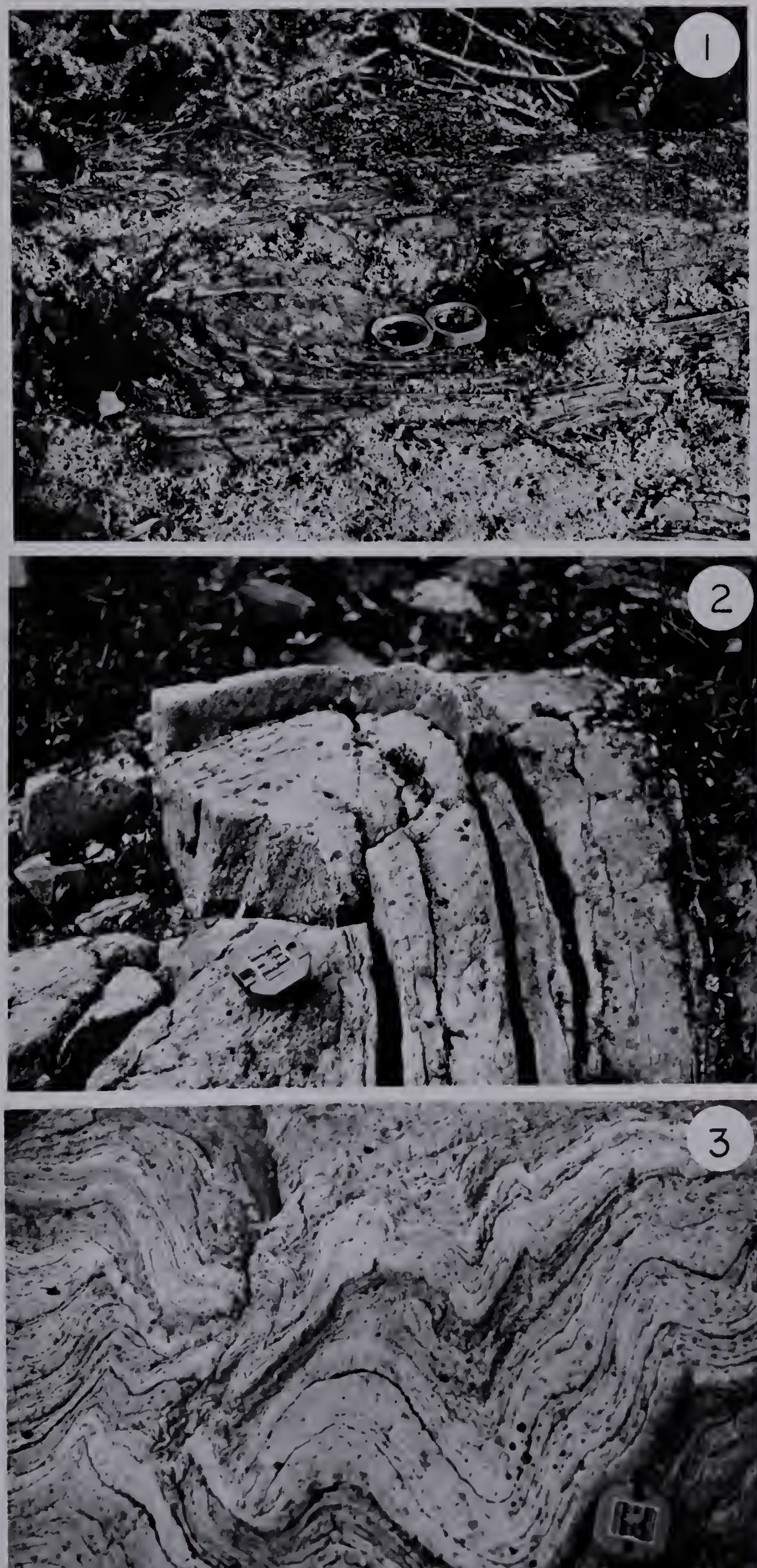
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PLATE XXIII

1. Quartzite and biotite-muscovite-quartz schist (unit 8). Re-folded (?) minor folds are shown. The large fold in the centre of the photograph has a curved but nearly horizontal axial surface and its axis has a very shallow plunge. The smaller fold immediately to the right has a nearly vertical axial plane it its axis has a similarly shallow plunge. The complex fold style may be attributable to considerable flowage of the schist. 55° 40' 57" N, 106° 02' 46" W. Sandfly Lake area (East Half).

2.&3. Quartzite and biotite-muscovite-quartz schist. Complex minor folds are shown. Thicker layers of quartzite (left side of photographs) show little deformation. The parts of the outcrop consisting mainly of schist have deformed plastically and flow folds resembling ptygmatic folds occur. 55° 37' 28" N, 106° 05' 27" W. Sandfly Lake Area (East Half). The lens cap (Plate XXII,3) is 2 inches in diameter.


1


2


3

APPENDIX XI : MODAL AND CHEMICAL ANALYSES AND NORMS

The following tables provide a complete listing of all modal and chemical analyses carried out for rocks from the thesis area. Barth mesonorms are given for analysed metamorphic rocks and C.I.P.W. norms are given for analysed intrusive rocks. The modal analyses, analytical techniques, and normative calculations are discussed in Appendices I, II, and III respectively.

Table XXVI Modal analyses, chemical analyses, and mesonorms for meta-arkose belonging to the "older metamorphic rocks" and for petrologically similar rocks.

Sample Number

	614-39-10a	614-40-8a[3]	614-40-8b[3,5]	614-40-8c[3,5]	614-69-1
Quartz	40	43	26	46	47
K-feldspar	16	21	22	21	12
Plagioclase	7	3	48	31	9
(An content)	(24)	(12)	(15)	(19)	(16)
Muscovite	37	31	2	2	30
Biotite	tr[1]	M[2]	1	--	M
Chlorite	--	--	--	--	tr
Garnet	tr	--	--	--	--
Apatite	tr	tr	tr	--	tr
Zircon	tr	--	--	--	tr
Sphene	tr	tr	tr	tr	tr
Opaques	tr	2	1	M	tr
SiO_2		75.0	72.5		
TiO_2		0.21	0.08		
Al_2O_3		14.03	16.48		
Fe_2O_3		2.11	0.97		
MnO		0.03	0.01		
MgO		0.7	--		
CaO		0.20	1.44		
Na_2O		1.18	5.32		
K_2O		5.65	3.36		
Total		99.1	100.2		
Rb (ppm)		111	30		
Sr (ppm)		37	105		
Q		44.5	23.6		
Or		31.9	19.2		
Ab		11.0	47.3		
An		0.3	6.8		
C		6.3	1.7		
Bi		4.3	0.7		
Mt		0.9	0.4		
Ti		0.5	0.2		

Table XXVI (continued)

	Sample Number			
	624-102-1b[5]	614-30-8a[4]	624-5-11b[4]	624-16-5a[4]
Quartz	50	49	43	37
K-feldspar	23	18	22	31
Plagioclase	21	M	tr	10
(An content)	(17)	(15)	( )	(14)
Muscovite	6	33	35	21
Biotite	--	--	--	1
Chlorite	--	--	--	--
Garnet	--	--	--	--
Apatite	tr	tr	tr	tr
Zircon	tr	tr	--	--
Sphene	--	--	--	tr
Opaques	1	tr	tr	tr
SiO_2		73.6		
TiO_2		0.06		
Al_2O_3		19.37		
Fe_2O_3		1.57		
MnO		0.01		
MgO		--		
CaO		0.04		
Na_2O		0.83		
K_2O		6.91		
Total		102.4		
Rb (ppm)		151		
Sr (ppm)		66		
Q		39.1		
Or		40.0		
Ab		7.5		
An		--		
C		11.5		
Bi		1.2		
Mt		0.7		
Ti		0.1		

1. Trace (less than 0.4 per cent)
2. Minor (0.4 to 0.7 per cent)
3. From the same outcrop
4. From immediately below the quartz-pebble meta-conglomerate (unit 7) belonging to the Meyers Lake Group. Stratigraphic position uncertain.
5. Boulder or cobble

Table XXVII : Modal analyses, chemical analyses, and mesornorms for hornblende-biotite rocks and amphibolite belonging to the "older metamorphic rocks" and for petrologically similar rocks.

	Sample Number				
	614-24-12	614-28-11[1]	614-36-5	614-37-11	614-63-4
Quartz	13	M[2]	2	tr[3]	31
K-feldspar	--	3	--	--	4
Plagioclase	44	30	32	53	41
(An content)	(35)	(37	(40)	(44)	(36)
Biotite	16	8	10	9	13
Hornblende	23	53	51	35	8
Chlorite	--	--	--	--	--
Clinopyroxene	--	4	--	--	--
Epidote	5	--	4	1	4
Allanite	tr	tr	--	--	tr
Opaques	--	--	tr	2	tr
Apatite	tr	tr	tr	tr	tr
Sphene	tr	M	tr	tr	tr
Zircon	--	--	--	--	--
Carbonate	--	--	tr	--	--
SiO_2	57.8		47.2		69.0
TiO_2	0.91		0.76		0.35
Al_2O_3	17.02		14.49		13.79
Fe_2O_3	6.59		13.01		3.79
MnO	0.08		0.23		0.06
MgO	5.5		9.8		2.7
CaO	4.70		8.09		4.82
Na_2O	4.52		2.90		4.08
K_2O	1.80		3.00		1.30
Total	98.6		99.4		97.6
Sr (ppm)	514				198
Rb (ppm)	83				25
Q	11.5		--		33.0
Or	--		4.4		--
Ab	40.8		4.8		37.7
An	6.9		10.2		8.5
C	4.5		--		2.5
Bi	13.6		13.3		10.0
Ho	20.0		21.5		6.5
Ac	--		--		--
Bk	--		34.0		--
Hy	--		--		--
Di	--		--		--
Mt	1.8		3.6		1.1
Ti	2.0		1.6		0.8

Table XXVII (continued)

	614-S3[1]	614-64-10[5]	624-21-5a[5]	624-55-3	624-67-9a[1]
Quartz	24	tr	10	6	tr
K-feldspar	23	--	3	--	--
Plagioclase	37	27	32	48	9
(An content)	(35)		(34)	(39)	(33)
Biotite	9	6	34	15	1
Hornblende	7	63	15	29	89
Chlorite	tr	--	--	--	--
Clinopyroxene	--	--	--	--	--
Epidote	--	1	5	tr	tr
Allanite	--	--	--	tr	--
Opaques	tr	1	tr	2	tr
Apatite	tr	tr	tr	tr	tr
Sphene	tr	2	--	tr	tr
Zircon	tr	--	--	--	--
Carbonate	--	--	--	--	--
SiO_2		41.5			47.6
TiO_2		1.32			0.53
Al_2O_3		14.78			9.94
Fe_2O_3		13.54			10.16
MnO		0.15			0.21
MgO		7.8			14.1
CaO		11.68			10.86
Na_2O		1.85			0.97
K_2O		1.48			0.58
Total		94.1			95.0
Sr (ppm)					60
Rb (ppm)					15
Q		--			--
Or		9.5			--
Ab		0.5			8.5
An		19.4			--
C		--			--
Bi		--			5.2
Ho		35.3			65.5
Ac		--			14.4
Bk		25.7			2.5
Hy		--			0.2
Di		2.9			--
Mt		4.1			3.0
Ti		3.0			1.2

1. From outside of eastern fold belt. Does not belong to the "older metamorphic rocks".
2. Minor (0.4 to 0.7 per cent).
3. Trace (less than 0.4 per cent).
4. Includes chlorite.
5. Interlayered with acidic meta-volcanic (?) rocks.

Table XXVIII : Modal analyses, chemical analysis, and mesonorm for knobby biotite-plagioclase gneiss belong;ing to the "older metamorphic rocks"

	Sample Number			
	614-38-12	624-16-6	624-62-19	624-81-5
Quartz	17	19	7	18
K-feldspar	--	tr	10	--
Plagioclase	49	54	47	53
(An content)	(17)	(18)	(33)	(25)
Biotite	34	27	32	29
Hornblende	--	--	4	tr
Opaques	tr	tr	tr	tr
Apatite	tr	tr	tr	tr
Zircon	tr	tr	tr	tr
SiO_2				62.6
TiO_2				0.59
Al_2O_3				15.46
Fe_2O_3				4.96
MnO				0.08
MgO				5.2
CaO				1.60
Na_2O				4.41
K_2O				2.99
Total				97.9
Sr (ppm)				135
Rb (ppm)				59
Q				20.6
Or				3.3
Ab				39.9
An				6.0
C				3.1
Bi				25.0
Mt				1.4
Ti				1.3

Table XXIX : Modal analyses, chemical analyses, and mesonorms for biotite gneiss and schist belonging to the "older metamorphic rocks" and for petrologically similar rocks

	Sample Number		
	624-56-15	634-52-1[1]	634-55-5[1]
Quartz	25	19	9
K-feldspar	--	11	--
Plagioclase	49	54	53
(An content)	(35)	(32)	(38)
Biotite	26	16	36
Hornblende	--	tr	3
Chlorite	--	--	tr
Apatite	tr	tr	tr
Zircon	--	tr	tr
Opaques	tr	tr	tr
Sphene	tr	--	--
SiO_2	66.6	68.6	
TiO_2	0.45	0.34	
Al_2O_3	13.46	15.69	
Fe_2O_3	5.38	3.26	
MnO	0.10	0.03	
MgO	4.0	2.1	
CaO	3.44	2.64	
Na_2O	3.76	3.20	
K_2O	1.93	2.34	
Total	99.1	97.3	
Sr (ppm)	469	148	
Rb (ppm)	44	62	
Q	27.4	31.9	
Or	1.2	6.8	
Ab	34.3	32.3	
An	12.3	12.2	
C	--	3.4	
Bi	16.8	11.8	
Ho	5.4	--	
Mt	1.7	0.9	
Ti	1.0	0.8	

[1] From outside of eastern fold belt. Does not belong to the "older metamorphic rocks".

Table XXX : Modal analyses, chemical analysis, and mesonorm for acidic meta-volcanic (?) rocks belonging to the "older metamorphic rocks"

	Sample Number 614-67-3	614-95-4	624-21-5b	624-88-3
Quartz	27	30	26	10
K-feldspar	23	42	39	14
Plagioclase	41	23[1]	21	39
(An content)	(17)	(16)	(29)	(22)
Biotite	8	5	11	36
Hornblende	--	--	3	--
Chlorite	--	tr	--	--
Apatite	tr	tr	tr	tr
Zircon	--	tr	tr	--
Sphene	tr	tr	--	
Opaques	M	tr	tr	2[2]
Epidote	tr	tr	--	tr
Allanite	tr	tr	--	tr
Carbonate	--	--	--	tr
SiO_2	72.7			
TiO_2	0.23			
Al_2O_3	14.98			
Fe_2O_3	1.57			
MnO	0.03			
MgO	0.7			
CaO	1.44			
Na_2O	3.90			
K_2O	4.93			
Total	100.5			
Sr (ppm)	217			
Rb (ppm)	83			
Q	26.1			
Or	25.1			
Ab	34.9			
An	6.4			
C	0.9			
Bi	6.3			
Mt	0.7			
Ti	0.5			

1 Includes 4 per cent sericite

2 Includes sphene

Table XXXI : Modal analyses, chemical analyses, and mesonorms for biotite-cordierite-sillimanite-(garnet) and biotite-garnet-(sillimanite)schist, gneiss, and granulite belonging to the "cordierite-garnet rocks".

	Sample Number					
	614-19-1c	614-19-7[1]	614-19-8c	614-43-2b	624-63-12b	624-Y-7
Quartz	18	48	8	29	1	11
K-feldspar	24	42	33	4	12	2
Plagioclase	6	7	2	52	tr	5
(An content)	(31)	(24)	(33)	(36)	(--)	(35)
Biotite	13	3	39	12	36	23
Garnet	15	tr	--	3	31	39
Cordierite	24	--	17	--	17	20
Sillimanite	M	tr	2	tr	2	tr
Apatite	tr	tr	--	tr	tr	tr
Zircon	--	tr	tr	tr	tr	tr
Sphene	tr	--	tr	--	--	--
Graphite	tr	--	--	--	--	tr
Opaques	M	--	--	tr	tr	tr
Chlorite	tr	M	tr	--	--	tr
SiO_2	63.0	77.5				51.2
TiO_2	1.07	0.08				1.58
Al_2O_3	18.41	10.03				18.16
Fe_2O_3	7.65	2.77				13.34
MnO	0.06	0.04				0.36
MgO	4.0	--				7.9
CaO	0.76	0.32				1.12
Na_2O	1.42	1.38				0.30
K_2O	3.44	5.41				3.27
Total	99.8	97.5				98.1
Sr (ppm)	91	76				36
Rb (ppm)	107	65				125
Q	38.8	47.5				29.8
Or	5.8	32.5				--
Ab	13.1	13.2				2.9
An	1.0	1.5				--
C	13.8	1.7				16.3
Bi	24.1	2.3				32.7
Ho	--	--				0.1
Hy	--	--				11.0
Mt	2.2	1.2				4.0
Ti	2.3	0.2				3.5

[1] Quartzo-feldspathic ("arkosic") variety

Table XXXII : Modal analyses, chemical analyses, and mesonorms of hornblende-biotite-clinopyroxene gneiss, hypersthene amphibolite, and clinopyroxene amphibolite

	Sample Number			
	614-41-9[1]	614-89-4[2]	614-100-1[2]	624-Y-3[3]
Quartz	10	3	4	--
Plagioclase	36	23	15	--
(An content)	(46)	(46)	(47)	(--)
Biotite	10	--	4	--
Hornblende	19	61	53	74.4
Clinopyroxene	24	--	--	25.4
Hypersthene	--	10	24	--
Opaques	tr	2	tr	0.2
Graphite	tr	--	--	--
Apatite	tr	--	tr	--
Zircon	tr	--	--	--
Carbonate	tr	--	--	--
SiO_2	55.5	45.4		50.9
TiO_2	0.26	1.98		0.54
Al_2O_3	14.0	12.46		7.19
Fe_2O_3	5.46	14.78		9.78
MnO	0.10	0.21		0.20
MgO	8.2	8.75		13.6
CaO	11.76	10.64		15.20
Na_2O	1.92	1.49		0.87
K_2O	0.68	0.61		0.48
Total	97.9	96.3		98.8
Sr (ppm)	240	73		83
Rb (ppm)	27	7		--
Q	13.4	--		1.0
Or	4.1	--		--
Ab	17.7	12.3		8.0
An	16.0	4.1		--
C	--	0.5		--
Bi	--	6.1		4.6
Ho	32.4	66.0		44.1
Ac	--	--		4.5
Bk	--	3.2		--
Di	14.5	--		34.0
Mt	1.3	4.4		2.8
Ti	0.6	4.4		1.0

1 Belongs to the "cordierite-garnet rocks"

2 Hypersthene amphibolite (sub-unit 6a)

3 Clinopyroxene amphibolite (sub-unit 6b)

Table XXXIII : Modal analyses, chemical analyses, and mesonorms for quartzite, feldspathic quartzite, and calcareous quartzite belonging to the Meyers Lake Group

	Sample Number				
	614-22-19a[1]	614-26-5[2]	614-38-5[3]	614-46-6[4]	614-70-3[1]
Quartz	74	66	64	91	75
K-feldspar	20	25	14	3	16
Plagioclase	tr	M	4	2	tr
(An content)	(--)	(--)	(31)	(31)	(--)
Muscovite	6	8	tr	3	8
Biotite	tr	--	--	M	--
Chlorite	--	--	M	tr	--
Actinolite	--	--	16	--	--
Epidote	--	--	tr	--	--
Apatite	tr	tr	tr	tr	tr
Sphene	tr	tr	M	--	tr
Zircon	tr	tr	tr	tr	tr
Tourmaline	tr	--	--	tr	--
Opaques	tr	tr	tr	tr	tr
Carbonate	--	--	--	--	--
SiO_2	92.2		89.7	97.2	
TiO_2	0.06		0.19	0.03	
Al_2O_3	6.48		4.78	2.53	
Fe_2O_3	0.49		1.46	0.59	
MnO	0.01		0.03	0.01	
MgO	--		1.6	--	
CaO	0.08		0.82	0.07	
Na_2O	0.12		0.58	0.7	
K_2O	2.91		1.77	1.18	
Total	102.3		100.9	101.7	
Sr (ppm)	27		35	14	
Rb (ppm)	49		27	28	
Q	72.0		74.6	90.1	
Or	24.1		7.4	7.4	
Ab	1.1		5.4	0.7	
An	0.2		4.5	0.3	
C	2.1		0.4	1.2	
Bi	--		6.2	--	
Mt	0.4		1.1	0.4	
Il	--		--	--	
Ti	0.1		0.4	0.1	

Table XXXIII (continued)

	624-24-6a[3]	624-24-9[2]	624-56-24[4]	624-57-29[3]
Quartz	76	44	91	69
K-feldspar	9	13	8	13
Plagioclase	1	tr	--	--
(An content)	(36)	(--)	(--)	(--)
Muscovite	--	43	1	--
Biotite	--	--	tr	M
Chlorite	--	--	--	--
Actinolite	11	--	--	12
Epidote	--	--	--	6
Apatite	tr	tr	tr	tr
Sphene	tr	tr	--	tr
Zircon	tr	--	tr	--
Tourmaline	tr	1	tr	--
Opaques	tr	tr	tr	tr
Carbonate	2	--	--	--
SiO_2		74.1		
TiO_2		0.36		
Al_2O_3		17.74		
Fe_2O_3		1.49		
MnO		0.01		
MgO		0.6		
CaO		0.04		
Na_2O		0.15		
K_2O		7.31		
Total		101.8		
Sr (ppm)		33		
Rb (ppm)		130		
Q		42.3		
Or		41.8		
Ab		1.4		
An		--		
C		10.5		
Bi		3.0		
Mt		0.5		
Il		0.4		
Ti		0.1		

1 Grey feldspathic quartzite

2 Pink arkosic quartzite

3 Calcareous (actinolitic) quartzite

4 "Pure" quartzite

Table XXXIV : Modal analyses, chemical analyses, and mesonorms for biotite-muscovite-quartz schist belonging to the Meyers Lake Group

Mineral	Sample Number 614-25-7	614-38-6	614-46-9	614-47-9
Quartz	32	39	32	40
K-feldspar	--	M	--	2
Plagioclase	7	M	1	--
(An content)	(34)	(38)	(31)	(--)
Muscovite	29	32	24	44
Biotite	29	27	25	14
Andalusite	--	--	18	--
Sillimanite	--	--	M	--
Apatite	tr	tr	--	tr
Zircon	tr	tr	tr	tr
Sphene	--	tr	--	--
Tourmaline	tr	tr	tr	tr
Opaques	2	tr	tr	tr
Graphite	--	tr	tr	--
SiO_2	64.1		60.4	
TiO_2	0.89		0.71	
Al_2O_3	18.39		22.98	
Fe_2O_3	4.11		5.46	
MnO	0.02		0.04	
MgO	6.0		2.9	
CaO	0.43		0.20	
Na_2O	0.45		0.65	
K_2O	6.01		5.39	
Total	101.2		98.8	
Sr (ppm)	90		38	
Rb (ppm)	122		151	
Q	35.0		34.0	
Or	19.4		22.8	
Ab	4.1		6.0	
An	--		--	
C	12.3		18.1	
Bi	26.5		16.7	
Mt	1.1		1.4	
Il	0.4		0.6	
Ti	1.3		0.6	

Table XXXIV (continued)

	624-57-10	624-83-7	624-84-6	624-89-5	624-92-1
Quartz	37	12	35	22	42
K-feldspar	--	--	2	--	M
Plagioclase	--	28	17	--	--
(An content)	(--)	(32)	(36)	(--)	(--)
Muscovite	58	27	17	31	45
Biotite	5	33	29	38	13
Andalusite	--	--	--	9	--
Sillimanite	--	--	--	--	--
Apatite	tr	tr	tr	tr	tr
Zircon	tr	tr	tr	tr	tr
Sphene	--	--	--	tr	--
Tourmaline	--	tr	--	tr	tr
Opaques	tr	tr	tr	tr	tr
Graphite	tr	--	tr	--	--
SiO_2			63.9		
TiO_2			0.57		
Al_2O_3			13.67		
Fe_2O_3			7.75		
MnO			0.05		
MgO			3.8		
CaO			0.63		
Na_2O			1.10		
K_2O			5.58		
Total			97.1		
Sr (ppm)			56		
Rb (ppm)			128		
Q			33.3		
Or			20.4		
Ab			10.7		
An			1.4		
C			6.3		
Bi			24.6		
Mt			2.3		
Il			--		
Ti			1.2		

Table XXXV : Modal analyses, chemical analysis, and mesonorm for epidiorite

	Sample Number					
	614-27-1	614-33-1	624-4-8	624-12-8	624-24-12	624-65-7
Quartz	1	1	1	2	2	tr
K-feldspar	tr	tr	tr	--	4	--
Plagioclase	53	55	54	48	75	58
(An content)	(44)	(38)	(41)	(38)	(40)	(36)
Biotite	10	4	18	16	5	tr
Hornblende	31	39	25	34	13	41
Opaques	2	--	M	tr	tr	tr
Epidote	tr	--	1	--	M	--
Allanite	tr	--	--	--	--	--
Sphene	tr	1	M	tr	tr	tr
Apatite	3	tr	tr	tr	tr	tr

SiO_2	54.5
TiO_2	0.71
Al_2O_3	18.02
Fe_2O_3	6.82
MnO	0.09
MgO	7.6
CaO	8.32
Na_2O	3.65
K_2O	1.17
Total	100.9
Sr (ppm)	1102
Rb (ppm)	44

Q	2.7
Or	1.7
Ab	31.8
An	16.8
Bi	8.1
Ho	35.8
Mt	1.9
Il	1.0

Table XXXVI : Modal analysis, chemical analysis, and mesonorm of a sample (614-39-6) of anthophyllite-cordierite-biotite gneiss

Quartz	30	SiO_2	62.0	Q	31.1
Plagioclase	12	TiO_2	0.57	Ab	15.9
(An content)	(23)	Al_2O_3	15.23	C	11.5
Biotite	15	Fe_2O_3	6.37	Bi	14.4
Chlorite	7	MnO	0.16	Ho	3.8
Cordierite	22	MgO	10.0	Hy	21.0
Anthophyllite	14	CaO	0.88	Mt	1.8
Zircon	tr	Na_2O	1.74	Ti	1.2
Apatite	tr	K_2O	1.09		
Opaques	tr	Total	98.0		
		Sr (ppm)	47		
		Rb (ppm)	22		

Table XXXVII: Modal analyses, chemical analyses, and C. I. P. W. norms for the western granitic rocks

	Sample Number						
	614-22-9	614-28-6	614-28-8	614-78-18	624-53-5	624-97-3a[2]	624-97-3b[2]
Quartz	40	29	11	43	40	1	7
K-feldspar	41	29	29	37	32	54	48
Plagioclase	27	35	52	20	23	37	40
(An content)	(16)	(12)	(17)	(14)	(14)	(15)	(15)
Biotite	3	3	2	tr	6	2	3
Hornblende	--	4	5	--	2	6	1
Apatite	--	tr	tr	tr	tr	tr	tr
Sphene	tr	tr	tr	tr	tr	--	tr
Zircon	tr	tr	tr	tr	tr	tr	tr
Opaques	tr	tr		tr	tr	tr	tr
Allanite	tr	--	--	--	--	--	--
Epidote	tr	tr	3[1]	--	--	tr	--
Sericite	tr	tr	tr	tr	tr	tr	tr
Chlorite	--	--	--	--	tr	--	--
SiO_2		74.2			76.5		66.2
TiO_2		0.30			0.34		0.28
Al_2O_3		14.86			13.87		19.76
Fe_2O_3		2.91			2.98		2.72
MnO		0.08			0.04		0.07
MgO		--			--		--
CaO		0.93			0.72		1.20
Na_2O		4.30			2.40		4.50
K_2O		4.08			5.68		7.22
Total		101.7			102.5		101.9
Sr (ppm)		88			55		136
Rb (ppm)		82			180		78
Q		30.7			28.4		9.1
or		24.0			33.5		42.6
ab		36.3			20.2		38.0
an		4.6			3.6		6.0
C		1.6			3.5		2.3
hy		2.0			1.9		1.9
mt		1.5			1.6		0.7
il		0.6			0.6		0.5

1 Includes opaque minerals.
2 From the same outcrop. Collected about 5 feet apart.

Table XXXVIII: Modal analysis of a sample (614-44-10) of hornblende quartz diorite

Quartz	11
Plagioclase	62
(An content)	(33)
Biotite	5
Hornblende	22
Apatite	tr
Sphene	tr
Opaques	tr
Epidote	tr

Table XXXIX : Modal analyses, chemical analyses, and C. I. P. W. norms for the eastern granitic rocks

	Sample Number						
	614-31-8	614-84-4	614-85-1	614-101-5	624-10-5	634-42-1	634 87-3
Quartz	32	42	15	23	33	20	11
K-feldspar	31	1	1	tr	3	20	19
Plagioclase	34	51	64	65	54	58	57
(An content)	(27)	(32)	(31)	(30)	(30)	(26)	(28)
Biotite	2	7	20	8	10	2	12
Hornblende	--	--	--	3	tr	--	2
Apatite	tr	tr	tr	tr	tr	--	tr
Sphene	--	--	tr	--	tr	--	tr
Zircon	--	tr	tr	--	--	tr	--
Opaques	tr	tr	tr	tr	tr	tr	tr
Allanite	--	--	--	--	--	--	--
Epidote	--	tr	--	tr	tr	--	tr
Chlorite	tr	--	tr	tr	tr	tr	tr
Sericite	2	tr	tr	tr	tr	tr	tr
Carbonate	--	--	tr	tr	tr	--	--
SiO_2	74.2		64.2				61.8
TiO_2	0.12		0.49				0.81
Al_2O_3	14.80		18.81				17.31
Fe_2O_3	1.31		3.23				5.02
MnO	0.02		0.04				0.08
MgO	--		2.4				2.4
CaO	1.54		4.02				3.70
Na_2O	2.92		4.49				4.11
K_2O	5.32		1.60				4.15
Total	100.2		99.3				99.4
Sr (ppm)	524		903				508
Rb (ppm)	48		35				54
Q	32.9		19.3				9.6
or	31.4		9.5				24.5
ab	24.6		37.9				34.7
an	7.8		20.2				16.5
C	1.4		2.3				--
di	--		--				1.7
hy	0.9		6.6				8.1
mt	0.5		1.6				2.4
il	0.2		0.9				1.5

Table XL : Chemical analyses and C.I.P.W. norms for pegmatite and chemical analysis of vein quartz

	Sample Number			
	614-41-6b[1]	614-S2[1]	644-Y2-6[1]	624-59-17[2]
SiO_2	77.2	77.2	76.1	99.2
TiO_2	0.03	0.05	0.02	0.04
Al_2O_3	12.77	14.37	14.27	1.43
Fe_2O_3	0.66	0.61	0.47	0.49
MnO	0.01	0.01	0.01	0.01
MgO	--	--	--	--
CaO	1.40	0.33	0.91	0.02
Na_2O	2.75	2.70	3.21	0.04
K_2O	2.05	4.34	4.32	0.22
Total	96.9	99.6	99.3	101.5
Sr (ppm)	302	111	94	
Rb (ppm)	31	267	116	
Q	50.2	43.4	37.0	
or	12.1	25.6	25.5	
ab	23.2	22.8	29.1	
an	7.0	1.7	4.5	
C	1.3	4.5	2.7	
hy	0.4	0.4	0.4	
mt	0.4	0.3	0.3	
il	0.1	0.1	0.0	

[1] Pegmatite

[2] Vein quartz

PROVINCE OF SASKATCHEWAN

DEPARTMENT OF MINERAL RESOURCES

MINES BRANCH GEOLOGY DIVISION

1964

73-P-13-W

LEGEND

INTRUSIVE AND/OR PLUTONIC ROCKS

- 14 — Pegmatite
- 13 — Eastern granitic rocks (probably Hudsonian); equigranular, mainly grey granodiorite and biotite quartz diorite, in part quartz monzonite
- 12 — Western granitic rocks (probably pre-Hudsonian); equigranular, mainly pink, mainly quartz monzonite but probably ranging from granite to monzonite

METASOMATIZED AND MIGMATITIC ROCKS

- 11 — MIGMATITE COMPLEX. 11a, porphyroblastic potassium feldspar gneiss—augen gneiss—migmatite complex, probably derived mainly from hornblendic and biotitic rocks; 11b, porphyroblastic potassium feldspar gneiss—augen gneiss—migmatite, derived mainly from unit 4; 11c, migmatite derived mainly from hornblende and hornblende-biotite rocks; 11d, migmatite derived from garnet-biotite and garnet-cordierite-biotite rocks; 11e, migmatite derived mainly from biotitic rocks; 11f, mainly granitic gneiss, probably includes some gneissic granitic rocks 12

METAMORPHOSED ROCKS

Metamorphosed Intrusive Rocks

- 10 — Epidiorite, probably metamorphosed diorite to gabbro.

Meyers Lake Group

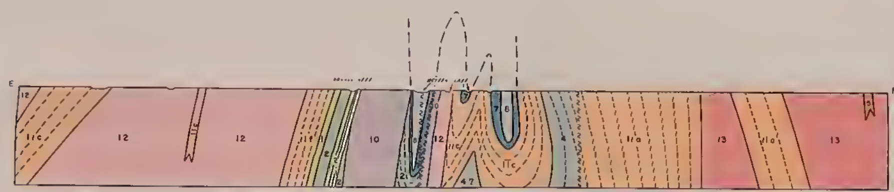
- 9 — Biotite-muscovite-quartz schist and gneiss, with or without andalusite, sillimanite, plagioclase and potassium feldspar, minor interlayered 8
- 8 — Quartzite, feldspathic quartzite, and calcareous (actinolitic) quartzite, minor interlayered 9, very minor interlayered 7
- 7 — Quartz-pebble meta-conglomerate, minor interlayered 8, 9

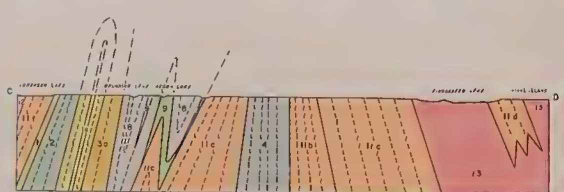
Metamorphic Rocks of Uncertain Stratigraphic Position

- 6 — Pyroxene amphibolites; 6a, hypersthene amphibolite
- 5 — Biotite-cordierite-sillimanite schist, gneiss, and granulite, with or without garnet, biotite-garnet schist, gneiss and granulite, with or without sillimanite, minor calc-silicate rocks

Older Metamorphic Rocks

- 4 — Acidic meta-volcanic (?) rocks, minor interlayered 2
- 3 — Biotitic rocks; 3a, knobby biotite-plagioclase gneiss, minor anthophyllite-cordierite-biotite gneiss
- 2 — Hornblende-biotite gneiss and granulite, minor amphibolite, very minor biotite schist and gneiss; 2a, mainly amphibolite; 2b, with minor 3a; 2c, with minor interlayered 4
- 1 — Meta-arkose, locally minor amphibolite, hornblende-biotite and biotite rocks; 1a, pebbly meta-arkose



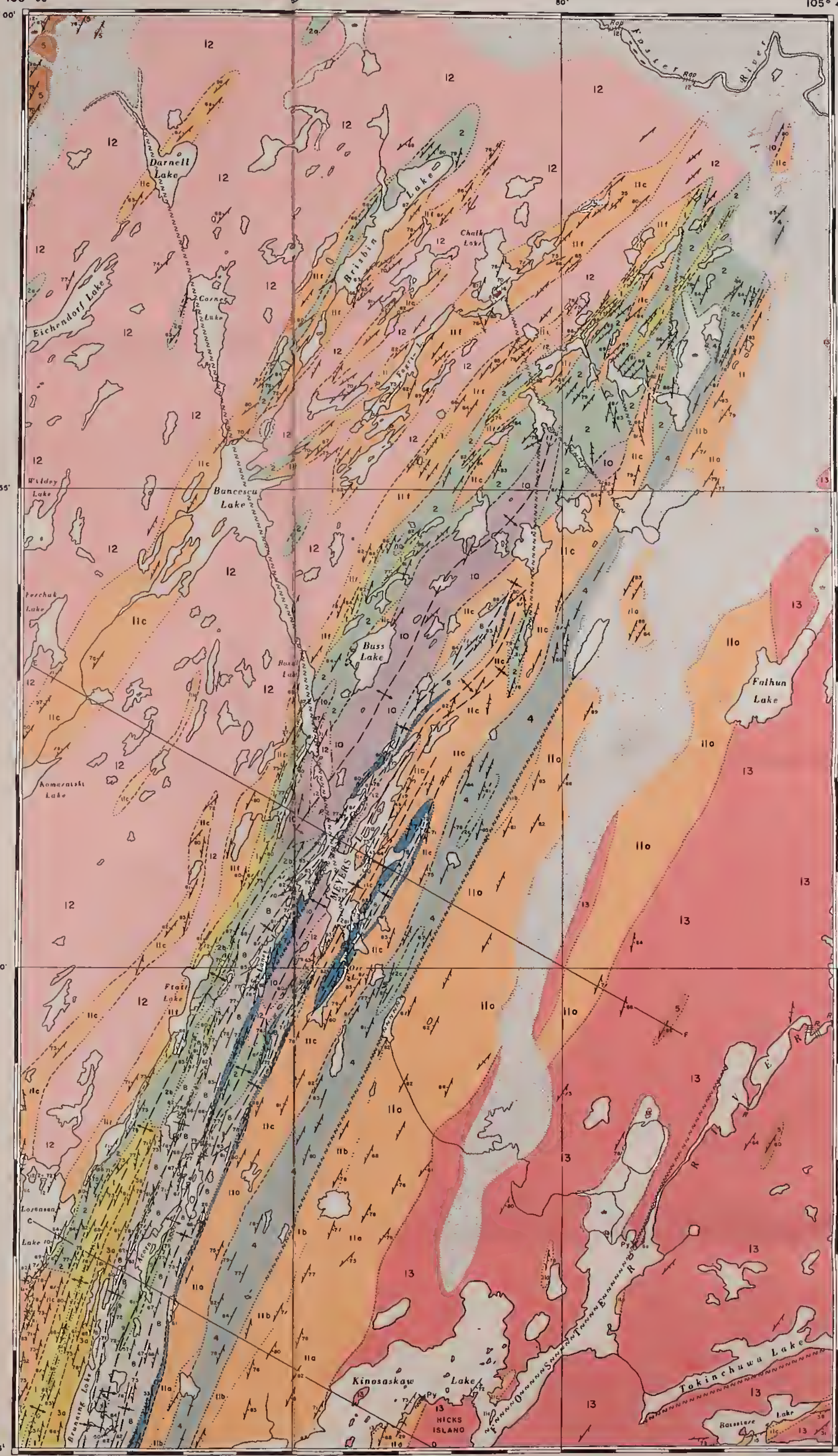


Geology by P. L. Money, 1961

To accompany Report No. 88

Base map prepared from vertical aerial photographs supplied by National Air Photographic Library, Ottawa

Approximate Magnetic Declination 20° East at centre of sheet, 1964. Decreasing 6' annually.



MAP No. 88A

EULAS LAKE

(WEST HALF)

SASKATCHEWAN

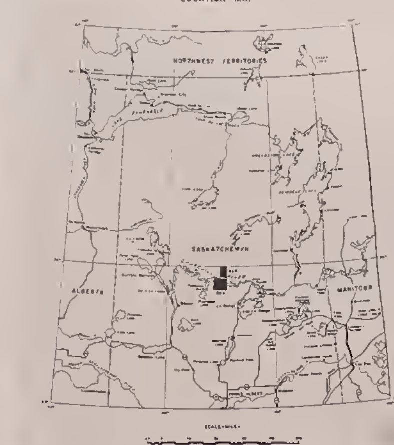
Scale 1: 63,360 or 1 inch = 1 mile

MILES

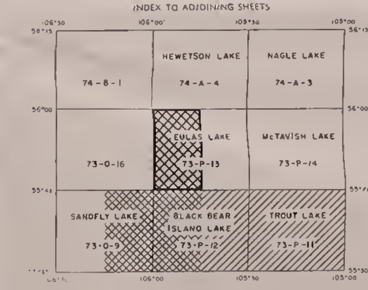
SYMBOLS

- Geological Boundary (defined, approximate, assumed)
- Fault, shear zone (position defined, approximate, assumed)
- Lineament
- Bedding, including interlayering of probably meta-volcanic and tuffaceous rocks (inclined, vertical)
- Schistosity and gneissosity (inclined, vertical, dip unknown)
- Lineation, mineral (inclined, horizontal)
  - stretched pebble (inclined, horizontal)
  - rodding (inclined, horizontal)
- Lineation: S-fold, Z-fold, crenulation (inclined)
  - Axis of minor syncline (inclined, horizontal)
- Anticline (trace of axial surface)
- Syncline (trace of axial surface)
- Mineralization: pyrite
- Glacial striae
- Area of glacial deposits
- Muskeg
- Rapids
- Portage
- Cabin

LOCATION MAP



INDEX TO ADJOINING SHEETS



PROVINCE OF SASKATCHEWAN

DEPARTMENT OF MINERAL RESOURCES

MINES BRANCH GEOLOGY DIVISION

1964

73-O-9-E and 73-P-12-W

LEGEND

INTRUSIVE AND/OR PLUTONIC ROCKS

Vein quartz, cross-hatched areas contain swarms of large quartz veins

Pegmatite; 14a, porphyritic pegmatite; cross-hatched areas contain more than 40 per cent pegmatite

13 — Eastern granitic rocks (probably Hudsonian); equigranular, mainly grey granodiorite and biotite quartz diorite, in part quartz monzonite; 13a, mainly grey porphyritic or porphyroblastic granodiorite

12 — Western granitic rocks (probably pre-Hudsonian); equigranular, mainly pink, mainly quartz monzonite but probably ranging from granite to monzonite; 12a, monzonite

METASOMATIZED AND MIGMATITIC ROCKS

11 — MIGMATITE COMPLEX 11a, porphyroblastic potassium feldspar gneiss—augen gneiss—migmatite complex, probably derived mainly from hornblendic and biotitic rocks; 11b, porphyroblastic potassium feldspar gneiss—augen gneiss—migmatite, derived mainly from unit 4; 11c, migmatite derived mainly from hornblende and hornblende-biotite rocks; 11d, migmatite derived from garnet-biotite and garnet-cordierite-biotite rocks; 11e, migmatite derived mainly from biotite rocks; 11f, mainly granitic gneiss, probably includes some gneissic granitic rocks (12)

METAMORPHOSED ROCKS

Metamorphosed Intrusive Rocks

10 — Epidiorite, probably metamorphosed diorite to gabbro

Meyers Lake Group

9 — Biotite-muscovite-quartz schist and gneiss, with or without andalusite, sillimanite, plagioclase and potassium feldspar, minor interlayered 8

8 — Quartzite, feldspathic quartzite, and calcareous (actinolitic) quartzite, minor interlayered 9, very minor interlayered 7

7 — Quartz pebble, meta-conglomerate, minor interlayered 8, 9

Metamorphic Rocks of Uncertain Stratigraphic Position

6 — Pyroxene amphibolites; 6b, clino-pyroxene amphibolite

5 — Biotite-cordierite-sillimanite schist, gneiss, and granulite, with or without garnet; biotite-garnet schist, gneiss, and granulite, with or without sillimanite; minor calc-silicate rocks

Older Metamorphic Rocks

4 — Acidic meta-volcanic (?) rocks, minor interlayered 2

3 — Biotitic rocks; 3a, knobby biotite-plagioclase gneiss, minor anthophyllite-cordierite-biotite gneiss; 3b, biotite schist and gneiss, locally minor hornblende-biotite rocks

2 — Hornblende-biotite gneiss and granulite, minor amphibolite, very minor biotite schist and gneiss; 2a, mainly amphibolite; 2b, with minor 3a; 2c, with minor interlayered 4

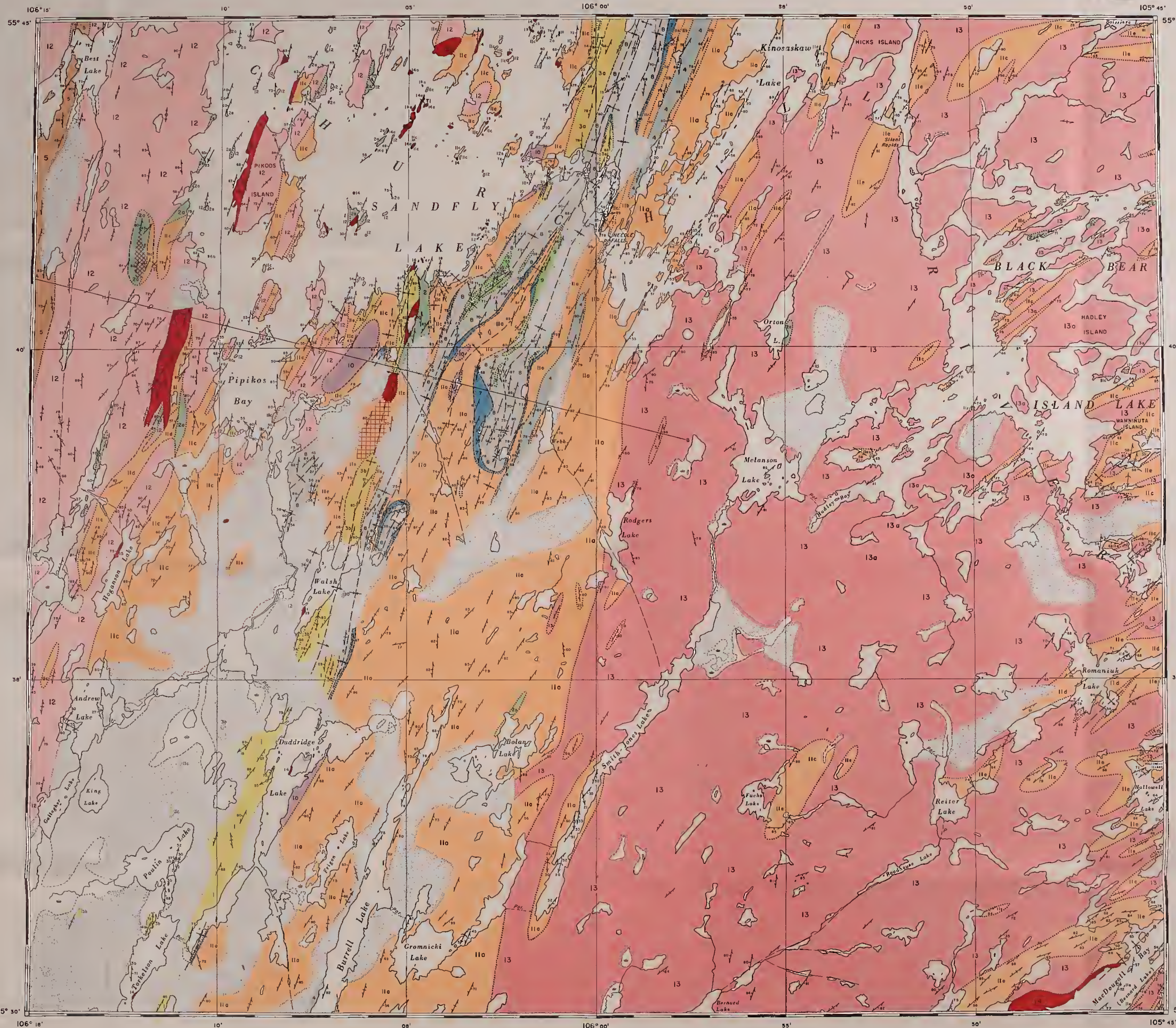
1 — Meta-arkose, locally minor hornblende-biotite and biotite rocks; 1a, pebbly meta-arkose

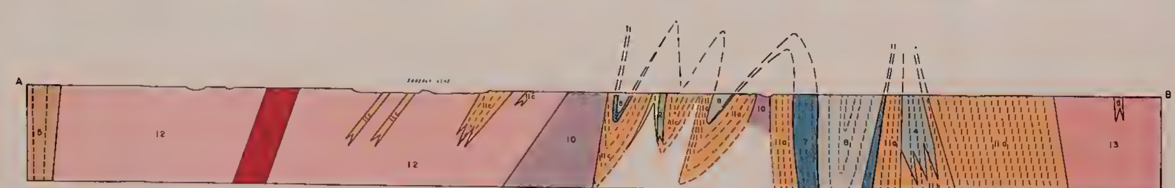
Geology by P. L. Money, 1962, 1963

To accompany Report No. 88

Base map prepared from vertical aerial photographs supplied by National Air Photographic Library, Ottawa

Approximate Magnetic Declination 19° East at centre of sheet, 1964 Decreasing 6' annually.





SYMBOLS

Geological Boundary (defined, approximate, assumed)

Fault, shear zone (position defined, approximate, assumed)

Lineament

Bedding, including interlayering of probably meta-volcanic and tuffaceous rocks (inclined, vertical)

Schistosity and gneissosity (inclined, vertical, dip unknown)

Lineation: mineral (inclined, horizontal)

stretched pebble (inclined, horizontal)

rodding (inclined, horizontal)

Lineation: S-fold, Z-fold, crenulation (inclined)

minor syncline (inclined, horizontal)

Anticline (trace of axial surface)

Syncline (trace of axial surface)

Mineralization: pyrite

tourmaline

Glacial striae

Area of glacial deposits

Muskeg

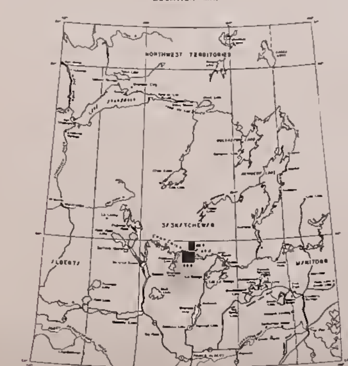
Rapids

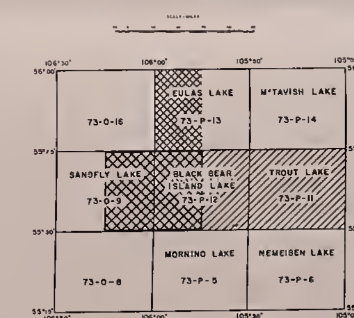
Falls

Portage

Cabin

LOCATION MAP





MAP No. 88B

SANDFLY LAKE (EAST HALF)

AND

BLACK BEAR ISLAND LAKE

(WEST HALF)

SASKATCHEWAN

Scale 1:63,360 or 1 inch = 1 mile

Miles 1 0 1 2 3 Miles